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MET35 --- ELECTRICAL AND ELECTRONICS ENGINEERING

OBJECTIVES

- *To understand the construction and operation of Transformers.*
- *To understand the construction and operation of Induction machines.*
- *To understand the construction and operation of Alternators.*
- *To acquire knowledge about operational amplifiers and its applications.*
- *To acquire knowledge about 555 IC and its applications*

UNIT – I: Transformers

EMF Equation – Equivalent circuit – Voltage regulation - OC and SC Test – Efficiency– Condition for maximum efficiency – All day efficiency – Autotransformer –Introduction to three phase Transformer.

UNIT – II: AC Machines

Theory and operation of 3 phase Induction motor - constructional details – starting methods – speed control methods – principle of operation of single phase Induction motor – stepper motor – AC series motor – Applications.

UNIT – III: Alternators

Alternators - construction - Operating principle - alternators on No load – Alternators on Load - Phasor diagram - Losses – Efficiency-voltage regulation by EMF method –Parallel operation of alternators.

UNIT – IV: Electronics

Op. Amp. – Characteristics – Inverting amplifier - Non-inverting amplifier - differentiation integration I/V converter - V/I converter - Instrumentation amplifier –adder – subractor – First order low pass filter and High pass filter using op. Amp.

UNIT – V

Advantages of ICs - pin configurations of 555 IC - Design of Astable and mono-stable multi-vibrator using 555 IC - design of counters using FF-UP/DOWN counters– -Ring counters -Multiplexes –De multiplexes.

Text Books:

1. I. J. Nagrath & D. P. Kothari, Electric Machines, IV Edition, Tata Mc. Graw-Hill Education, New Delhi, 2010
2. Ramakant A Gayakward, Operational Amplifiers and Linear Integrated circuits, 4th Edition, PHI Learning, Delhi, 2009.

Reference Books:

1. Albert Malvino and David Bates, “Electronic Principles”, 7th Edition, Tata Mc. Graw Hill, New Delhi, 2006.
2. B. L. Theraja & A. K. Theraja, A Textbook of Electrical Technology: AC and DC Machines, Volume - II, 23rd Edition, S. Chand & Company, New Delhi, 2012.

MET35 --- ELECTRICAL AND ELECTRONICS ENGINEERING

2 MARKS (QUESTION & ANSWERS)

UNIT 01 (Transformer)

1. **Define transformer?**

   Transformer is a static machine which transfers electric power from one circuit to another circuit without a change in its frequency.

2. **Briefly explain the principle of operation of transformers.**

   A transformer consists of two coils which are in mutual inductance. When AC supply is given to one of the coils, an alternating flux is set up, which is linked with the second coil. Due to this alternating flux there is a mutually induced emf produced in the second coil. If the second coil is closed, current flows in it and so electric energy is transferred magnetically from the first coil to the second coil.

3. **What are the parts of a transformer?**

   The transformer has mainly following parts.
   - Primary winding – the coil to which the AC supply is given
   - Secondary winding – the coil from which output is taken and given to load.
   - Laminated Core – this acts as a mechanical support to the coils as well as provides magnetic path for the flux.

4. **What are the types of core in transformer?**

   There are two types of core in transformer
   - Shell type
   - Core type

5. **What is an ideal transformer?**

   An ideal transformer is the one which has no losses i.e., its windings have no ohmic resistance, there is no magnetic leakage and hence which has no I^2R and core losses. The efficiency of an ideal transformer is 100%.

6. **Give the emf equation of the transformer.**

   The emf induced in the transformer is given by

$$E_1 = 4.4.4\ f\ N_1\ \phi_m$$
$$E_2 = 4.4.4\ f\ N_2\ \phi_m$$

Where, E_1 *is the emf induced in the primary winding.*
E_2 *is the emf induced in the secondary winding.*
N_1 *is the number of turns in the primary winding.*
N_2 *is the number of turns in the secondary winding*
ϕ_m *is the maximum flux produced.*
f *is the frequency in Hz.*

7. **What are the losses occurring in a transformer.**

   The losses occurring in a transformer are

   a) Core loss – loss occurring in the core of the transformer. This has two components.
   - Hysteresis loss – The loss occurring due to the magnetization characteristics of the core.
   - Eddy current loss – The loss occurring due to the eddy current produced in the core.

b) Copper loss (I^2R loss) – loss occurring in the windings of the transformer. This has two components.

- Primary copper loss – The loss occurring due to the current flowing through the primary winding.
- Secondary copper loss – The loss occurring due to the current flowing through the secondary winding.

8. **What are the components of primary no-load current?**

The primary no-load current consists of mainly two components. They are,

a) Magnetizing current (I_m) – Produces flux in the core and hence magnetizes the core.

b) Core loss component current (I_c) – compensates for the core losses.

9. **What is the purpose of laminating the core in a transformer?**

To reduce the eddy current loss in the core of the transformer.

10. **Does transformer draw any current when secondary is open? Why?**

Yes, it (primary) will draw the current from the main supply in order to magnetize the core and to supply for iron and copper losses on no load. There will not be any current in the secondary since secondary is open.

11. **Define voltage regulation of a transformer?**

When a transformer is loaded with a constant primary voltage, the secondary voltage decreases for lagging PF load, and increases for leading PF load because of its internal resistance and leakage reactance. The change in secondary terminal voltage from no load to full load expressed as a percentage of no load or full load voltage is termed as regulation.

12. **Define all day efficiency of a transformer?**

It is computed on the basis of energy consumed during a certain period, usually a day of 24 hrs. all day efficiency=output in kWh/input in kWh tor 24 hrs.

13. **Why transformers are rated in kVA?**

Copper loss of a transformer depends on current & iron loss on voltage. Hence total losses depends on Volt-Ampere and not on PF. That is why the rating of transformers are in kVA and not in kW.

14. **What are the typical uses of auto transformer?**

- To give small boost to a distribution cable to correct for the voltage drop.
- As induction motor starter.

15. **What is the turns ratio and transformer ratio of transformer?**

Turns ratio = N_2/ N_1

Transformer ratio = $E_2/E_1 = I_1/ I_2 = K$

UNIT 02 (AC Machines)

1. **What are types of 3- phase induction motor?**

- Squirrel cage induction motor
- Slip ring induction motor

2. **What is slip of an induction motor?**

The slip speed expressed as the ratio of synchronous speed is defined as slip.

Percentage slip S=Ns-N/Ns*100

3. **Why the rotor slots of a 3-phase induction motor are skewed?**

The rotor slots of a three -phase induction motor are skewed

- To make the motor run quietly by reducing the magnetic humming
- To avoid the locking tendency of the rotor

4. **Why the induction motor is called asynchronous motor?**

- Since the induction motor runs always at a speed lesser than synchronous speed, it is called asynchronous motor.

5. **Mention different types of speed control of slip ring induction motor?**
    - By changing supply frequency
    - By changing the number of stator poles
    - By rotor rheostat control
    - By operating two motors in cascade
    - By slip recovery scheme
6. **Name the two windings of a single-phase induction motor.**
    - Running winding
    - Starting winding.
7. **What is the function of capacitor in a single-phase induction motor?**
    - To make more phase difference between the starting and running winding.
    - To improve the power factor and to get more torque.
8. **Give the names of three different types of single-phase motor.**
    - Split phase motor
    - Shaded pole motor.
    - Single phase series motor.
    - Repulsion motor.
9. **What is the use of shading ring in a pole motor?**

The shading coil causes the flux in the shaded portion to lag behind the flux in unshaded portion of pole. This gives in effect a rotation of flux across the pole face and under the influence of this moving flux a stating torque is developed.

10. **State any four use of single-phase induction motor.**
    - Fans,
    - Wet grinders,
    - Vacuum cleaners,
    - Small pumps,
    - compressors,
    - Drills
11. **What are the types of starters?**
    - Stator rheostat,
    - Autotransformer
    - Star to Delta switch
    - Rotor resistance starter.
    - D.O.L
12. **Mention the starter suitable for rotor side control (slip ring induction motor).**

    Rotor resistance starter is the only starter used in the rotor side of three phase induction motor

13. **Mention the starter suitable for squirrel cage induction motor.**
    - Stator rheostat,
    - Autotransformer
    - Star to Delta switch
    - D.O.L
14. **What are the advantages of capacitor-start capacitor run motor**
    - High starting torque
    - High efficiency
    - High power factor
15. **Mention the applications of stepper motor**
    - Robotics
    - Computer peripherals
    - Facsimile machine
    - Aerospace

UNIT 03 (Alternator)

1. What is an alternator

An alternator (or) AC generator is a synchronous machine which converters mechanical energy into electrical energy and produces alternating e.m.f

2. What is the necessity for predetermination of voltage regulation?

Most of the alternators are manufactured with large power rating and large voltage ratings. Conduction load test is not possible for such alternators. Hence other indirect methods of testing are used and the performance can be predetermined at any desired load currents and power factors.

3. What is the principle of an alternator

The alternator works on the principle of Faradays law of electromagnetic induction. Whenever a conductor links with a magnetic field either the conductor is moving (or) the field is moving, an e.m.f is induced in the conductor.

4. Why e.m.f method called Pessimistic method

The value of voltage regulation obtained by e.m.f method is always more than the actual value; therefore it is called Pessimistic method

5. Why is the stator core of Alternator laminated?

The stator core of Alternator is laminated to reduce eddy current loss.

6. Why are Alternators rated in kVA and not in kW?

The continuous power rating of any machine is generally defined as the power the machine or apparatus can deliver for a continuous period so that the losses incurred in the machine gives rise to a steady temperature rise not exceeding the limit prescribed by the insulation class. Apart from the constant loss incurred in Alternators is the copper loss, occurring in the 3 –phase winding which depends on I^2R, the square of the current delivered by the generator. As the current is directly related to apparent – power delivered by the generator, the Alternators have only their apparent power in VA/kVA/MVA as their power rating.

7. What are the causes of changes in voltage in Alternators when loaded?

Variations in terminal voltage in Alternators on load condition are due to the following three causes:

- Voltage variation due to the resistance of the winding, R
- Voltage variation due to the leakage reactance of the winding, X_t

8. What are the main parts of Alternator?

- Stator core
- Salient or non-salient rotor field winding
- Rotor shaft
- Bearings
- Internal cooling Fan etc.

9. Write down conditions for parallel operation of two Alternators?

Both the Alternator should have same

- Voltage
- Frequency
- Phase difference(3 phase)

10. Mention the different methods finding voltage regulation.

- Synchronous impedance method (EMF method)
- Ampere turn method (MMF method)
- ZPF method

11. Mention different methods of synchronization of single phase alternator.

- Dark lamp method
- Bright lamp method

12. What are the advantages of having rotating field system?

- Better insulation

- Ease of current collection
- Increased armature tooth strength.
- More rigid construction
- Reduced armature leakage reactance.
- Lesser number of slip rings.

UNIT 04 (Electronics)

1. **What are the advantages of ICs over discrete circuits?**
    - Minimization & hence increased equipment density.
    - Cost reduction due to batch processing.
    - Increased system reliability
    - Improved functional performance.
    - Matched devices.
    - Increased operating speeds
    - Reduction in power consumption
2. **What is OPAMP?**

    An operational amplifier is a direct coupled high gain amplifier consisting of one or more differential amplifiers, followed by a level translator and an output stage. It is a versatile device that can be used to amplify ac as well as dc input signals & designed for computing mathematical functions such as addition, subtraction, multiplication, integration & differentiation
3. **List out the ideal characteristics of OPAMP?**
    - Open loop gain infinite
    - Input impedance infinite
    - Output impedance low
    - Bandwidth infinite
    - Zero offset, ie., $V_o=0$ when $V_1=V_2=0$
4. **Mention some of the linear applications of op – amps**
    - Adder,
    - subractor,
    - Voltage to current converter,
    - Current to voltage converters,
    - Instrumentation amplifier,
    - Analog computation,
    - Power amplifier, etc.
5. **Define slew rate.**

    The slew rate is defined as the maximum rate of change of output voltage caused by a step input voltage. An ideal slew rate is infinite which means that op-amp’s output voltage should change instantaneously in response to input step voltage.
6. **What is the need for an instrumentation amplifier?**

    In a number of industrial and consumer applications, the measurement of physical quantities is usually done with the help of transducers. The output of transducer has to be amplified So that it can drive the indicator or display system. This function is performed by an instrumentation amplifier.
7. **List the features of instrumentation amplifier**:
    - low DC offset
    - low output impedance
    - high gain stability with low temperature co-efficient
    - high CMRR

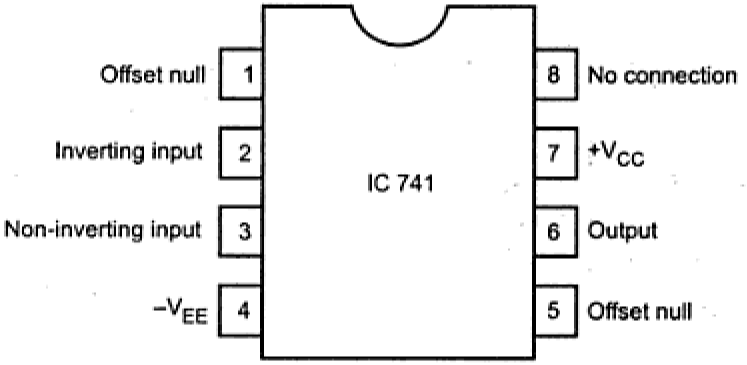
8. Define CMRR.

The ability of a differential amplifier to reject a common mode signal is expressed by a ratio called common mode rejection ratio denoted as CMRR

"The ratio of the differential voltage gain (A_d) to common mode voltage gain (A_c)"

$$\boxed{\text{CMRR} = \rho = \left|\frac{A_d}{A_c}\right|}$$

9. Draw the pin configuration of IC741.



10. Compare inverting and non-inverting amplifier.

Ideal inverting amplifier	*Ideal non-inverting amplifier*
Voltage gain = R_f / R_1	Voltage gain = $1+ (R_f / R_1)$
The output is inverted with respect to input	No phase shift between input and output
The voltage gain can be adjusted as greater than, equal to (or) less than one	The voltage gain is always greater than one
The input impedance is R_1	The input impedance is extremely large

11. What are the D.C Characteristics of Op-amp?

- Input Bias current.
- Input offset current.
- Input offset voltage.
- Thermal Drift.

12. What are the A.C Characteristics of Op-amp?

- Slew rate.
- Frequency response.

UNIT 05

1. What are the applications of 555 Timer?

- Astable multivibrator
- Monostable multivibrator
- Missing pulse detector
- Linear ramp generator
- Frequency divider
- Pulse width modulation
- FSK generator
- Pulse position modulator

2. List the applications of 555 timer in Astable mode of operation:

- FSK generator
- Pulse-position modulator

3. List the applications of 555 timer in monostable mode of operation.

- ™ missing pulse detector
- ™ Linear ramp generator
- ™ Frequency divider
- ™ Pulse width modulation.

4. Define 555 IC?

The 555 timer is an integrated circuit specifically designed to perform signal generation and timing functions.

5. List the basic blocks of IC 555 timer?

- A relaxation oscillator
- RS flip flop
- Two comparator
- Discharge transistor.

6. List the features of 555 Timer?

- It has two basic operating modes: Monostable and Astable
- It is available in three packages. 8 pin metal can, 8 pin dip, 14 pin dip.
- It has very high temperature stability.

7. Define duty cycle?

The ratio of high output and low output period is given by a mathematical parameter called duty cycle. It is defined as the ratio of ON Time to total time

8. Explain the function of pin2 in IC555 timer?

The pin 2 is trigger pin. The inverting input of comparator 2 is brought out as trigger.it is compared with 1/3Vcc & when it is below this level, the output of the comparator 2 goes high which is given to reset input of R-S flip flop.

9. Explain the function of pin 5 in IC555 timer?

This pin is inverting input of the comparator 1.The voltage divider holds the voltage of this pin at 2/3Vcc.This is the reference level for the comparator 1 with which the threshold is compared. So generally external control voltage at pin 5 is not used. Only when the reference required is other than 2/3Vcc for the comparator 1 then it is used.

10. Which are the packages in which IC555 is available?

- Dual in line package
- Flat package

11. Compare monostable & Astable multivibrator.

Sl. No	Monostable multivibrator	Astable multivibrator
1	It has only one stable state	It has no stable state
2	Trigger is required for the operation	Trigger is not required for the operation
3	Two components R & C are required with IC 555 to obtain the circuit.	Three components R , R & C are required with IC555 to obtain the circuit

12. Define counter.

A counter is a register capable of counting the number of clock pulses arriving at its clock input. Count represents the number of clock pulses arrived. On arrival of each clock pulse, the counter is incremented by one. In case of sown counter it is decremented by one.

13. Define shift register.

The binary information (data) in a register can be moved from stage to stage within the register or into or out of the register upon application of clock pulses. This type of movement or shifting is essential for certain arithmetic and logical operations used in microprocessors. This gives rise to a group of registers called shift registers.

14. Mention the applications of shift registers.

- Delay line
- Serial to parallel converter
- Parallel to serial converter
- Pseudo random binary sequence generator
- Sequence detector

15. What is shift register counter?

A shift register can also be used as a counter. A shift register with the serial output connected back to the serial input is called shift register counter. The most common shift register counters are the ring counter and the Johnson counter.

1. TRANSFORMER

EMF Equation – Equivalent circuit – Voltage regulation - OC and SC Test – Efficiency – condition for maximum efficiency – All day efficiency – Autotransformer –Introduction to three phase Transformer

Part-A (2 Marks)

1. **Why transformer rating is expressed in terms of KVA (NOV/2014)**

Copper loss depends on current and iron loss depends upon voltage. Hence the total loss in a transformer depends upon volt-ampere (VA) only and not on the phase angle between voltage and current i.e. it is independent of load power factor. That is why the rating the transformer is KVA and not in KW.

2. **What are the losses in single phase transformer?**

- Core (or) iron losses
  - (a) Hysteresis loss (b) Eddy current loss
- Copper loss

3. **What are turns ratio and transformation ratio of transformer?**

$$\text{Turns ratio} = \frac{N_2}{N_1}$$

$$\text{Transformation ratio} = \frac{E_2}{E_1} = \frac{I_1}{I_2} = K$$

4. **Define "All day Efficiency" of a transformer.**

The ratio of output in kWh to input in Kwh of a transformer over a 24 hour period is known as all-day efficiency.

$$\text{All day Efficiency}=\frac{\text{kwh output in 24 hours}}{\text{kwh input in 24 hours}}$$

5. **How can the iron loss are minimized in a transformer.**

The iron loss in a transformer is made up of hysteresis loss and eddy current loss. Hysteresis loss can be minimized by using steel of high silicon content for the transformer core. The eddy current loss can be minimized by using very thin laminations of transformer core.

6. **What are the advantages of OC and SC tests on the transformers?**

- The power required to carry out these test is very small as compared to the full load output of the transformer.
- These tests enable us to determine the efficiency of the transformer accurately at any load and power factor without actually loading the transformer.
- The short circuit test is used to determine $R_{o1} and\ X_{o1} (\ or\ R_{o2} and\ X_{o2})$. By using this data, we can find out voltage drop and voltage regulation of the transformer.

7. **Does transformer draw any current when secondary is open? Why? (NOV-2014)**

The transformer draws no- load current when secondary is open. The transformer works on the principle of electromagnetic induction, since both primary and secondary windings are wound on the same core, the primary is connected to the ac supply, it forms a closed path that ensures no-load current that establish flux in the core.

8. **The no-load ratio of a 50HZ, single phase transformer is 6000/250V. Estimate the number of turns in each winding if maximum flux is 0.06Wb in the core.(APRIL-2014)**

$E_1=4.44f\phi_m N_1$ and $E_2=4.44f\phi_m N_2$

$N_1= (6000)/ (4.44\times50\times0.06) = 450$

$N_2= (250)/ (4.44\times50\times0.06) = 19$

9. **Define voltage regulation of a transformer.(APRIL-2014)**

Because of the voltage drop across the primary and secondary impedances it is observed that the secondary terminal voltage drops from it's no load value (E_2) to load value (V_2) as load and load current increases. This decrease in the secondary terminal voltage expressed as a fraction of the no load secondary terminal voltage is called regulation of a transformer.

10. **A 220/110 V, 50 Hz ideal transformer has 166 turns in its primary. What is the peak value of flux (NOV/2013)**

$E_1=4.44f\phi_m N_1$

$\phi_m= E_1/(4.44fN_1)$

$\phi_m= (220)/ (4.44\times50\times166) = 0.006$Wb

11. **Write down the condition for maximum efficiency of the transformer (APRIL/2013) (NOV/2013)**

The condition for maximum efficiency of the transformer is core loss equal to copper loss.

12. **Define transformation ratio. (APRIL/2013)**

The voltage transformation ratio is

$$\frac{E_2}{E_1}=\frac{V_2}{V_1}=\frac{I_1}{I_2}=\frac{N_2}{N_1}=K$$

13. **Classify the transformer according to the construction (NOV/2012)**

- Core type transformer
- Shell type transformer
- Berry type transformer

14. **Define a transformer. (APRIL/2012)**

The transformer works on the principle of electromagnetic induction. A transformer is an electrical device, having no moving parts, which by mutual induction transfers electric energy from one circuit to another at the same frequency, usually with changed values of voltage and current.

15. **What are the advantages of three phase transformer? (NOV/2012)**

- The cost of three phase transformer is around 15% less than single phase transformer bank
- It is weightless and occupies less space
- The bus bar structure, switch gear and other wiring for a three phase installation are simple
- It can be more easily transported
- The amount core material required is less.

16. **What is an autotransformer?**

Autotransformer is one in which one winding acts as both primary and secondary and energy transformation is carried out both electrically and magnetically.

17. **What are the advantages of autotransformer?**

- It has only one winding, so saving is in conductor material and cost.
- Continuously varying voltage can be obtained.
- Better voltage regulation.
- Higher efficiency and smaller in size.

18. **Mention some applications of an auto transformer. (APRIL/2012)**

- Used for starting of induction motors and synchronous motors
- Used in electrical testing laboratory
- Used as booster to raise the voltage in AC feeders

19. **What happens, if dc supply applied to the transformer?**

DC supply has no frequency, if frequency is zero, inductive reactance 2πfL is zero. Total impedance becomes very low. Thus winding will draw very high current; this may cause the burning of the winding.

20. **Why all day efficiency is lower than commercial efficiency?**

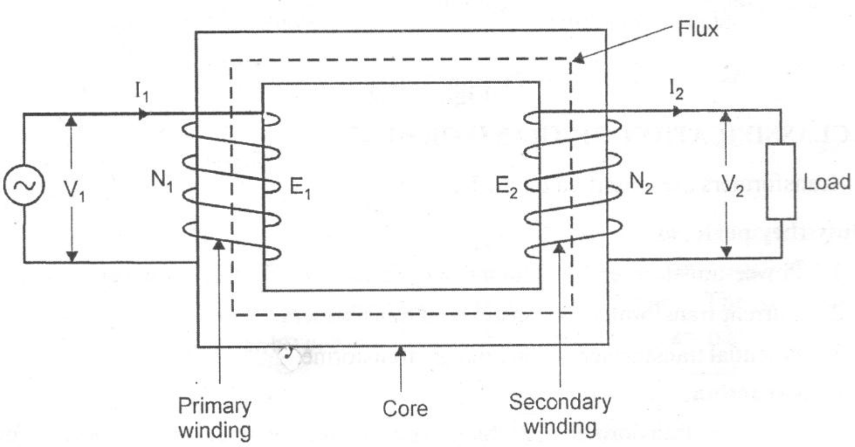
All day efficiency is based on energy, but the commercial efficiency is based on power. Time is involved in all day efficiency. So the efficiency is less than commercial efficiency.

Part –B (11 Marks)

1. State and explain the operating principle of a transformer.

(i) Transformer

The transformer works on the principle of electromagnetic induction. A transformer is an electrical device, having no moving parts, which by mutual induction transfers electric energy from one circuit to another at the same frequency, usually with changed values of voltage and current. It consists of two windings insulated from each other and wound on a common core made up of magnetic material.



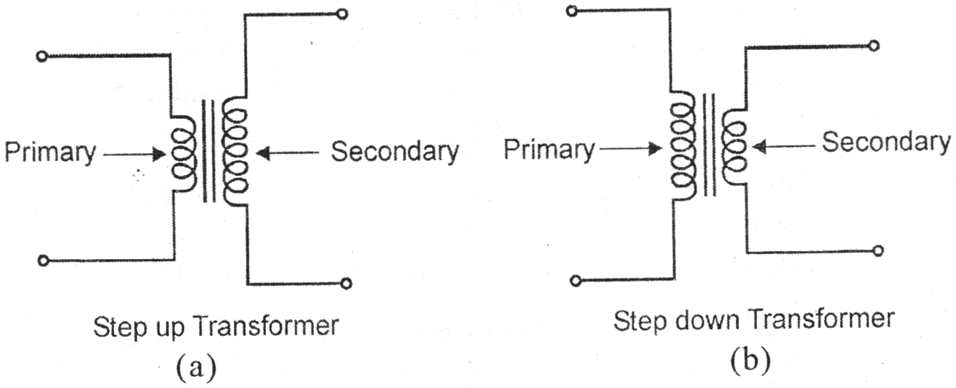
Alternating voltage is connected across one of the windings called the primary winding. In both the windings emf is induced by electromagnetic induction. The second winding is called the secondary winding. It is shown in the above figure.

(ii) WORKING PRINCIPLE OF A TRANSFORMER

The primary winding is connected to an AC source, an exciting current flows through it. As the current is alternating, it will produce an alternating flux in the core which will be linked by both the primary and secondary windings. The induce emf in the primary winding (E_l) is almost equal to the applied voltage V_1 and will oppose the applied voltage. The emf induced in the secondary winding (EZ) can be utilized to deliver power to any load connected across the secondary. Thus power is transferred from the primary to the secondary circuit by electromagnetic induction.

The flux in the core will alternate at the same frequency as the frequency of the supply voltage. The frequency of induced emf in secondary is the same as that of the supply, voltage. The magnitude of the emf induced in the secondary winding will depend upon its number of turns.

In a transformer, if the number of turns in the secondary winding is less than those in the primary winding, it is called a step-down transformer (Figure (b)), when the number of turns in the secondary winding is higher than the primary winding, it is called a step-up transformer (Figure (a)).



Step up Transformer
(a)

Step down Transformer
(b)

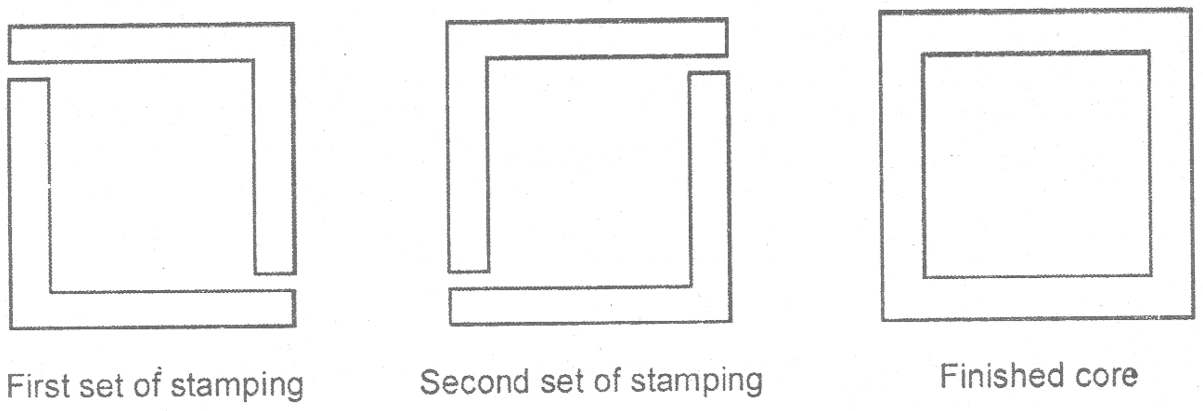
2. Describe the construction details of transformer and also explain the principle of operation with necessary diagram (11) (NOV/2014)

A transformer is a static device and its construction is simple as there are no moving parts. The main components of a transformer are

- The magnetic core.
- Primary and secondary windings.
- Insulation of windings.
- Expansion tank or conservator.
- Lead and tappings for coils with their supports, terminals and terminal insulators.
- Tank, oil, cooling arrangement, temperature gauge, oil gauge.
- Buchholz relay.
- Silica gel breather.

Magnetic Core

Magnetic circuit consists of an iron core. The transformer core is generally laminated and is made out of a good magnetic material like silicon steel. The thickness of laminations or stampings varies from 0.35 mm to 0.5 mm. The laminations are insulated from each other by coating then with a thin coat of varnish.



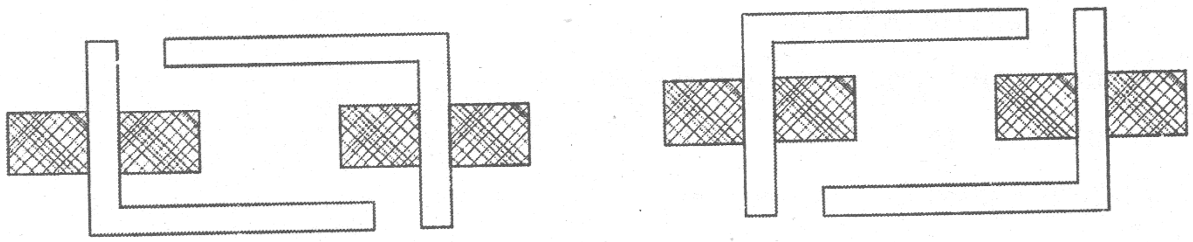
Various types of samplings and laminations employed in the construction of transformers are shown in above figure. Here the core surrounds the considerable part of coil. The joints are staggered to avoid continuous gap causing increase in magnetising current. If the joints are not staggered, the core will have less mechanical strength and during operation there would be undue humming noise. After arranging the laminations they are bolted together.

The two types of transformer cores are:

- Core type
- Shell type

a) Core type transformer

Here the windings surround a considerable part of core as shown in the below figure and has only one magnetic path. It has two limbs for the two windings and is made up of two L-type stampings as shown in below figure (a). The coils used usually are of cylindrical type and are usually wound. For transformers of higher rating stepped core with circular cylindrical coils are used. For transformers of smaller rating, a rectangular coil with core of square or rectangular cross section is used. Insulating cylinders are used to separate windings from the core and from each other.

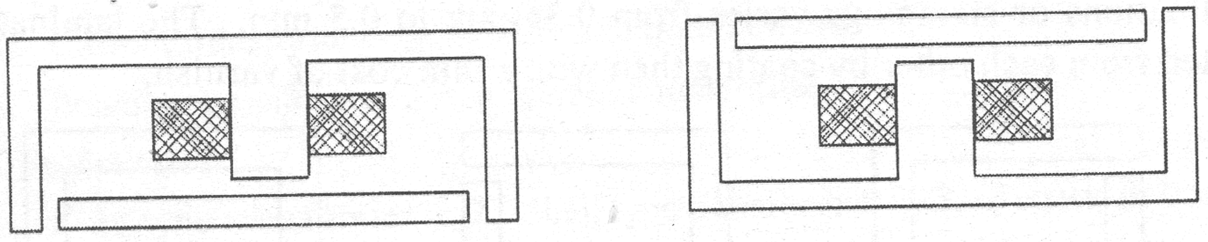


(a)

b) Shell type transformer

Here the core surrounds the considerable part of windings as shown in the below figure (b). The two windings are carried by central limb. The core is made up of E and I stamping (figure (b)) and has three limbs. It has two parallel paths for magnetic flux.

The coils used are of multilayer disc type and are former wound in the form of pan-cakes. Each layer is insulated from each other by paper.



(b)

Winding

There are two windings in a transformer. They are called primary and secondary windings. Generally the windings are made of copper.

Insulation

Paper is still used as the basic conductor insulation. Enamel insulation is used as the inter-turn insulation of low voltage transformers. For power transformers enamelled copper with paper insulation is also used.

Insulating Oil

The oil used in transformer protects the paper from dirt and moisture and removes the heat produced in the core and coils. It also acts as insulating medium. The oil must possess the following properties.

i) High dielectric strength.
ii) Free from inorganic acid, alkali and corrosive sulphur to prevent injury to the conductor or insulation.
iii) Low viscosity to provide good heat transfer.
iv) Free from sludging under normal operating conditions.
v) Good resistance to emulsion so that the oil may throw down any moisture entering the tank instead of holding it in suspense.

Expansion Tank or Conservator

A small auxiliary oil tank may be mounted above the transformer and connected to main tank by a pipe. Its function is to keep the transformer tank full of oil despite expansion or contraction of the coil with the changes in temperature. A small pipe connection between the gas space in the expansion tank and the cover of the transformer tank permits the gas above the oil in the transformer to pass into the expansion tank, so that the transformer tank will be completely filled with oil.

Temperature Gauge

Every transformer is provided with a temperature gauge to indicate hot oil or hottest spot temperature. It is self-contained weather proof unit made of alarm contacts. It is dial operated by bourdon gauge connected to a thermometer bulb located in the region of hottest oil.

Gauge

Every transformer is fitted with an oil gauge to indicate the oil level present inside tank. The oil gauge may be provided with an alarm contact with gives an alarm the oil level has dropped beyond permissible height due to oil leak or due to any other reason.

Relay

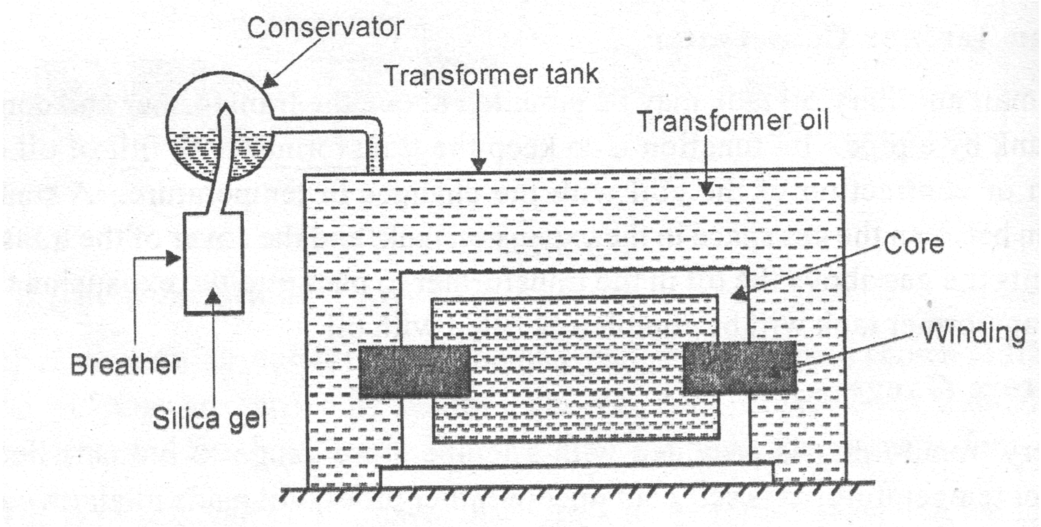
The first warning that a fault is present may be given by the presence of bubbles in the oil. If the transformer is fitted with a conservator and there are no pockets in which gas can collect, the gas bubbles will rise up the pipe joining the conservator to the tank. It is possible to mount gas operated relay in this pipe to give an alarm in case of minor fault and to disconnect the transformer from the supply mains in case of severe faults.

Breather

The simplest method to prevent the entry of the moisture inside the transformer tank is to provide chambers known as breather. The breather is filled with some drying agent, such as calcium chloride or silica gel. Silica gel or calcium chloride absorbs moisture and allows dry air to enter the transformer tank. The drying agent is replaced periodically as routine maintenance. The whole of the transformer tank and portion of conservator used filled with oil. The breather is connected on one side of the conservator. Thus a small surface area of transformer oil is exposed to the atmosphere through the breather.

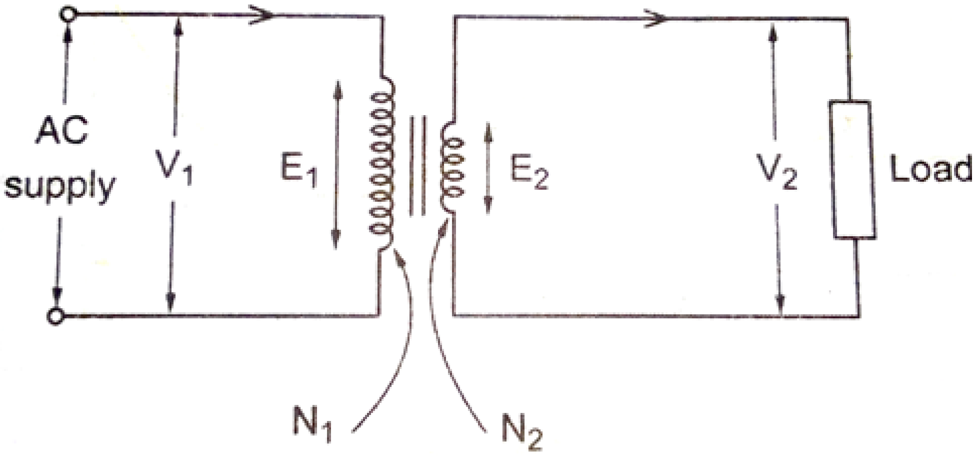
Bushings

Connections from the transformer windings are brought out by means bushings. Ordinary porcelain insulators can be used upto a voltage of 33kV. Above 33kV, capacitor and oil filled type of bushings are used. Bushings are fixed on the transformer tank.



3. **Derive the emf equation of a transformer (5) (APRIL 2012/APRIL/NOV/2014)**

Consider an alternating voltage (V_1) of frequency (f) is applied to primary winding of the transformer

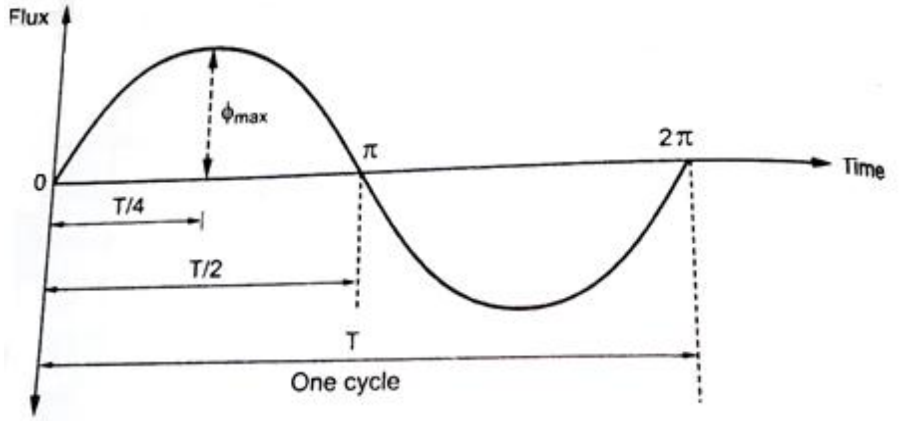


Let

- ✓ ϕ_m be the maximum value of flux in Weber
- ✓ f be the supply frequency in Hz
- ✓ N_1 is the number of turns in the primary winding
- ✓ N_2 is the number of turns in the secondary winding
- ✓ A be the area of core in m^2
- ✓ B_m be the maximum value of flux density in (wb/m^2)
- ✓ V_1 be the supply voltage across primary in volts
- ✓ V_2 be the terminal voltage across secondary in volts
- ✓ I_1 be the primary current in amps
- ✓ I_2 be the secondary current in amps

- ✓ E_1 be the EMF induced in primary winding in volts
- ✓ E_2 be the EMF induced in secondary winding in volts

Since the applied voltage is alternating in nature, the flux established is also an alternating one. From the figure given below, it is clear that the flux is attaining its maximum value in one quarter of the cycle (T/4), where T is the time in seconds.



We know that, T= 1/f, where f is the supply frequency

$$\text{Average EMF } (e) = \frac{d\varphi}{dt}$$

Where $d\phi = , \phi_m$

$$dt = \frac{1}{4f}$$

Average rate of change of flux= $\dfrac{\varphi_m}{\frac{1}{4f}} = 4f\,\phi_m$ volts

Average EMF induced per turn= average rate of change of flux= $4f\,\phi_m$ volts

RMS value= Form Factor × Average Value= 1.11 × Average Value

The RMS value of EMF induced/turn= $1.11 \times 4f\,\phi_m = 4.44f\,\phi_m$ volts

The primary and secondary winding having N_1 and N_2 turns respectively

RMS value of EMF induced in primary winding

$$E_1 = 4.44f\,\phi_m N_1 \text{ volts}$$

RMS value of EMF induced in secondary winding

$$E_2 = 4.44f\,\phi_m N_2 \text{ volts}$$

EMF equation in terms of flux density is given by

$$E_1 = 4.44f\ N_1 B_m A \ \text{ Volts and } E_2 = 4.44f\ N_2 B_m A \ \text{ volts}$$

Transformation Ratio

For an ideal transformer, $E_1 = V_1$ and $E_2 = V_2$

There is no voltage drop in the windings, $V_1 I_1 = V_2 I_2$

$$\frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1} = K$$

$$\frac{V_2}{V_1} = K \text{ ----- Voltage ratio}$$

$$\frac{E_2}{E_1} = K \text{ ----- Transformation ratio}$$

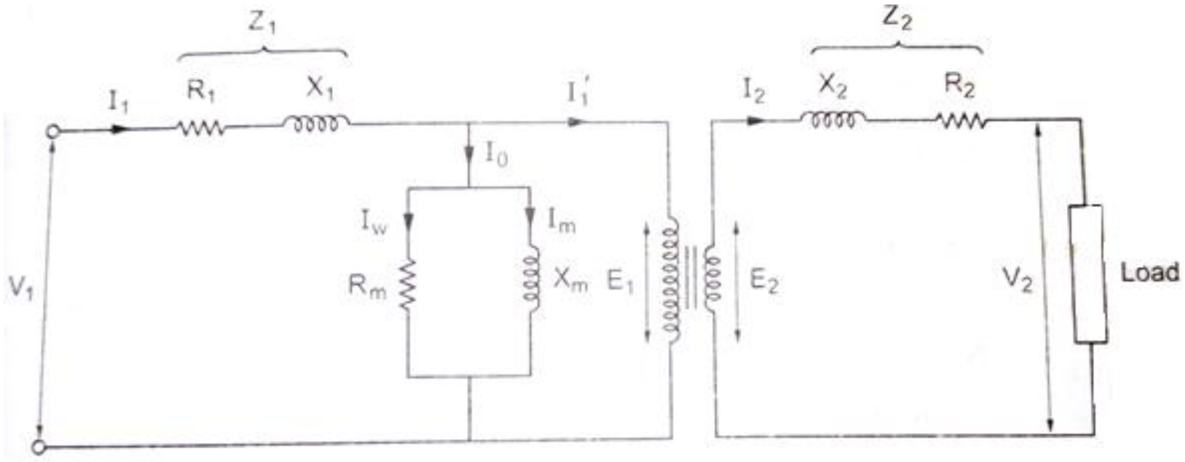
$$\frac{N_2}{N_1} = K \text{ ----- Turns ratio}$$

$$\frac{I_1}{I_2} = K \text{ ------ Current ratio}$$

4. Obtain the equivalent circuit of a transformer. **(NOV/2012/APRIL/2014)**

The equivalent circuit of any device can be helpful in predetermination of the behavior of the device under varying conditions of operation. The equivalent circuit for electromagnetic devices consists of a combination of resistances, inductances and capacitances. An actual transformer represented by two windings linked by a magnetic circuit. To estimate the performance of a transformer and to do simple calculation, a transformer is often represented by its equivalent circuit.

In this equivalent, the effects of the core and the windings are represented by equivalent circuit parameters



Representation of core by its electrical equivalent

- ✓ The core forms the path for the magnetic flux (ϕ_m), set up by a current (I_m) lagging E_1 by 90°. Hence the magnetizing component of the core is represented by a pure inductive reactance (X_m) connected across the EMF (E_1)
- ✓ Core loss is accounted by a current I_w in phase with E_1 which is represented by a resistance R_m connected across E_1

Primary current $\overline{I_1} = \overline{I_0} + \overline{I_1'}$

No-load primary current $\overline{I_0} = \overline{I_w} + \overline{I_m}$

Supply voltage= V_1

EMF induced in primary winding due to flux (ϕ_m) = E_1

The core loss component-= I_w

The magnetizing component= I_m

The magnetic loss components are R_m and X_m

- ✓ From no-load to full load, the core loss occurs in the transformer, so the magnetic loss components are connected in parallel

Representation of primary winding

The primary winding of a transformer is represented by its equivalent resistance (R_1) and leakage reactance (X_1)

Primary winding resistance= R_1 Ω

Primary leakage reactance= X_1 Ω

Primary winding impedance $Z_1 = \sqrt{R_1^2 + X_1^2}\ \Omega$

The difference between V_1 and E_1= I_1Z_1 Ω

Representation of secondary winding

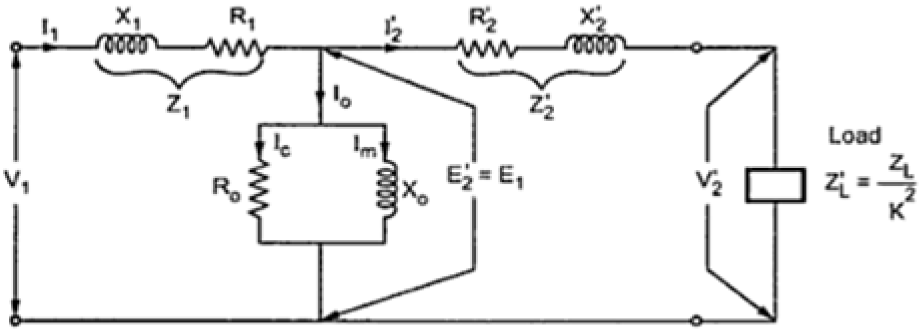
The secondary winding of a transformer is represented by its equivalent resistance (R_2) and leakage reactance (X_2)

Secondary winding resistance= R_2 Ω

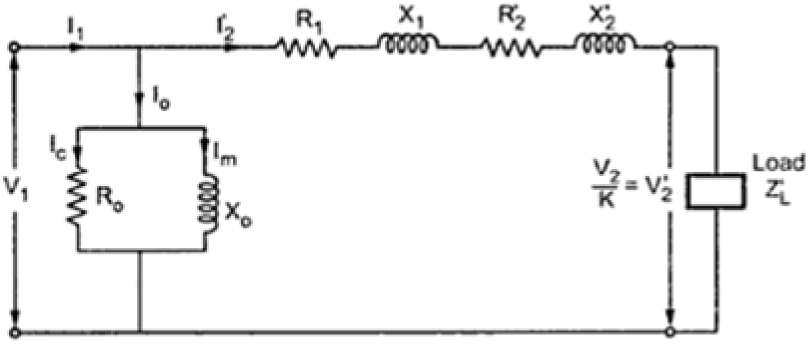
Secondary leakage reactance= X_2 Ω

Secondary winding impedance $Z_2 = \sqrt{R_2^2 + X_2^2}\ \Omega$

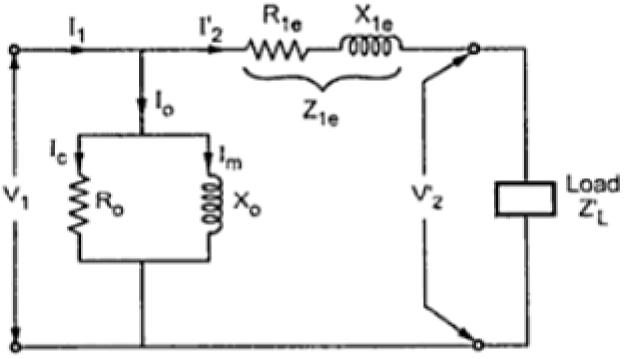
The difference between V_2 and E_2= I_2Z_2 Ω



Exact equivalent circuit of transformer with secondary quantities referred to primary side



Approximate equivalent circuit of transformer referred to primary side



$R_2{}' = \frac{R_2}{K^2}$ --- The secondary resistance referred to primary side

$X_2{}' = \frac{X_2}{K^2}$ --- The secondary reactance referred to primary side

$Z_2 = \frac{Z_2}{K^2}$ --- The secondary impedance referred to primary side

$I_2{}' = KI_2$ --- The secondary current referred to primary side

$E_2{}' = \frac{E_2}{K}$ --- The secondary induced EMF referred to primary side

$V_2{}' = \frac{V_2}{K}$ --- The secondary voltage referred to primary side

✓ The voltage drop due to primary and secondary winding resistance and reactance always vary with load current. Therefore it is connected in series

5. Explain OC and SC tests on single phase transformer. (APRIL/2012)

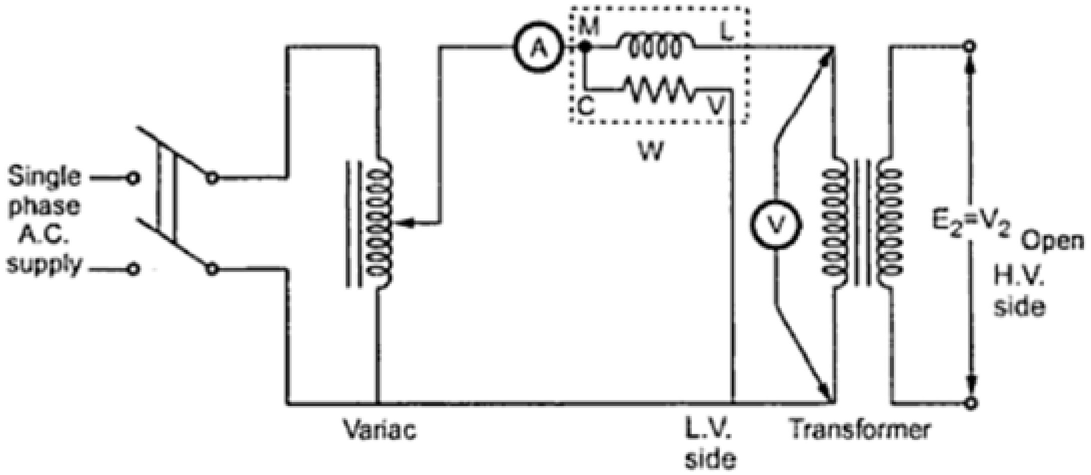
INDIRECT LOADING TESTS OF TRANSFORMERS

The efficiency and regulation of a transformer on any load condition and at any power factor condition can be predetermined by indirect loading method. In this method, the actual load is not used on transformer. But the equivalent circuit parameters of a transormer by conducting two tests on a transformer which are (i) open circuit test (ii) short circuit test

The parameters calculated from these test results are effective in determine the regulation and efficiecy of a transformer at any load and power factor condition, without actual loading the transformer.

The advantage of this method is that without much power loss the tests can be performed and results can be obtained.

(i) Open circuit Test



The transformer primary is connected to ac supply through ammeter, wattmeter and variac. The secondary of transformer is kept open. Usually low voltage side is used as primary and high voltage side as secondary to conduct OC test.

The primary is excited by rated voltage, which is adjusted precisely with the help of a variac. The wattmeter measures input power. The ammeter measures input current. The voltmeter gives the value of rated voltage applied at rated frequency. Sometimes a voltmeter may be connected across secondary to measure the secondary voltage which is $V_2= E_2$ when primary is supplied with rated voltage. As voltmeter resisitance is very high, though voltmeter is connected, secondary is treated to be open circuit as voltmeter current is always neglibibly small.

When the primary voltage is adjusted to its rated value with the help of variac, readings of ammeter and wattmeter are to be recorded.

V_0 = Rated voltage
W_0= Input power
I_0= Input current= no load current

As transformer secondary is open, it is on no load. So current drawn by the primary is no load current I_0. The two components of this no load current are,

$$I_m= I_0 \sin\phi_0$$
$$I_0= I_0 \cos\phi_0$$

Where $\cos\phi_0$= No load power factor

Hence power input can be written as $W_0= V_0I_0 \cos\phi_0$

As secondary is open, I_2=0. Thus it's reflected current on primary I_2 is also zero. So we have primary current $I_1= I_0$. The transformer no load current is very small, hardly 2 to 4% of its full load value. As I_2=0, secondary copper losses are zero. And $I_1=I_0$ is very low hence copper losses on primary are also very low. Thus the total copper losses in OC test are negligibly small. As against this the input voltage is at rated frequency, hence flux density in the core is at its maximum value. Hence iron losses at rated voltage. As output power is zero and copper losses are very low, the total input power is used to supply iron losses. This power is measured by the wattmeter (W_0). Hence the wattmeter in OC test gives iron losses which remain constant for all loads.

$$W_0= P_i= \text{Iron losses}$$
$$W_0= V_0I_0\cos\phi$$
$$\text{Cos}\varphi_0 = \frac{W_0}{V_0I_0} \text{ -No Load Power Factor}$$

Once $\cos\phi_0$ is known we can obtain

$$I_c=I_0 \cos\phi_0$$
$$I_m=I_0 \sin\phi_0$$

Once I_c and I_m are known

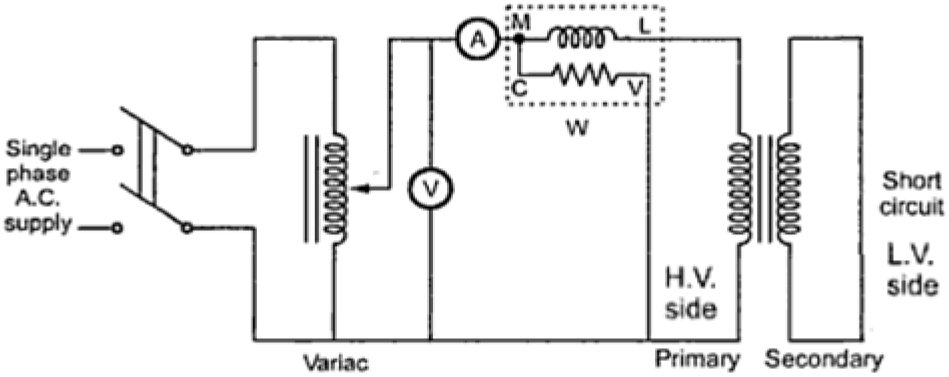
$$R_0 = \frac{V_0}{I_c}$$

$$X_0 = \frac{V_0}{Im}$$

The no load power factor $\cos\phi_0$ is very low, hence wattmeter used is low power factor meter type.

Short Circuit test (SC test)

In this test, primary is connected to ac supply through variac, ammeter and voltmeter. The secondary is short circuited with the help of thick copper wire or solid link. As high voltage side is always low current side, it is convenient to connect high voltage side to supply and shorting the low voltage side. As secondary is shorted, its resistance is very small and on rated voltage it may draw very large current. Such large current can cause overheating and burning of the transformer. To limit this short circuit current, primary is supplied with low voltage which is just enough to cause rated current to flow through primary which can be observed on ammeter.



Now the currents flowing through the windings are rated currents hence the total copper loss. Now the voltage applied is low which a small fraction of the rated voltage is. The iron losses are function of applied voltage. So the iron losses in reduced voltage test are very small. Hence the wattmeter reading is the power loss which is equal to full load copper losses as iron losses are very low.

$$W_{sc} = (P_{cu})\ F.L = \text{Full load copper loss}$$

From SC test readings

$$W_{sc} = V_{sc} I_{sc} \cos\phi_{sc}$$

$$\cos\varphi_{sc} = \frac{W_{sc}}{V_{sc} I_{sc}} \quad \text{----Short circuit power factor}$$

$$W_{sc} = I_{sc}^2 R_{01} = \text{copper loss}$$

$$R_{01} = \frac{W_{sc}}{I_{sc}^2}$$

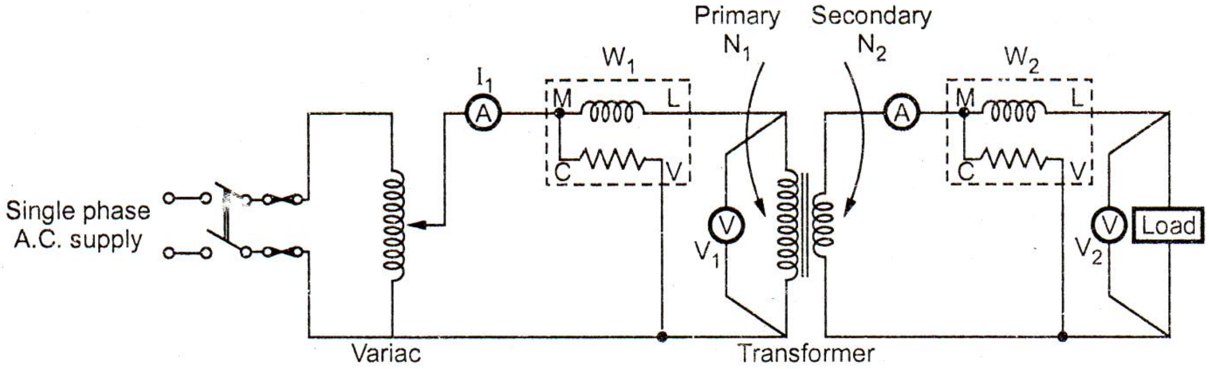
$$Z_{01} = \frac{V_{sc}}{I_{sc}} = \sqrt{R_{01}^2 + X_{01}^2}$$

$$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$$

Thus we get the equivalent circuit parameters R_{01}, X_{01} and Z_{01}. Knowing the transformation ration K, the equivalent circuit parameters refereed to secondary also can be obtained.

6. Explain load test on transformer

In this method the required load is directly connected to the secondary of the transformer. Hence this method is also called **direct loading test** on transformer. The various meters are connected on primary and secondary side of the transformer. Then the load is varied from no load to full load and the readings on the various meters are recorded. An ammeter, voltmeter and a wattmeter is connected on primary as well as secondary side of the transformer. The primary is connected to the supply through variac which is used to adjust primary voltage to its rated value at each load condition.



The load is to be varied from no load to full load in desired steps. At all time, keep primary voltage V_1 constant at its rated value with the help of variac. The following observation table is prepared.

W_1 = Input power to the transformer

W_2 = Output power delivered to the load

$\therefore$ $\% \eta = \frac{W_2}{W_1} \times 100$

The first reading is on no load for which $V_2 = E_2$

Thus at any other load, regulation can be obtained as

$\% R = \frac{E_2 - V_2}{V_2} \times 100$

Where V_2 is secondary terminal voltage at corresponding load. The graph of % η and % R on each load against load current I_L can be plotted.

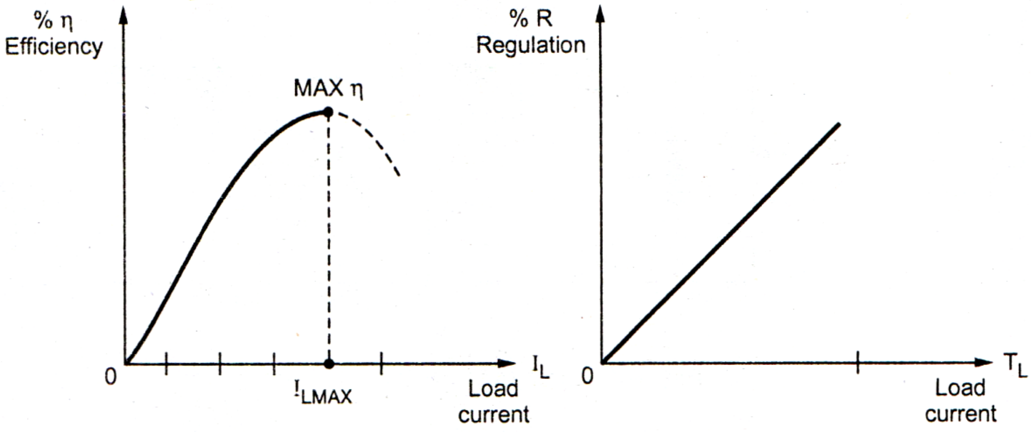


Fig. 4.23 Efficiency and regulation characteristics

The efficiency increases as load increases upto particular load. After that load, efficiency decreases as load increases. The regulation increases as the load increases as V_2 keeps on decreasing as the load increases.

Advantages and Disadvantages of Direct Loading

The important advantage of this method is that the results are accurate as load is directly used,

The **disadvantages** of this method are,

1. For large rating transformers, suitable load is difficult to obtain in the laboratory. It cannot be loaded upto its full load capacity in the laboratory.
2. There are large power losses during the test.

7. *Problem 1:* **Draw the equivalent circuit of a single phase 1100/220 v transformer on which the following results were obtained.**

   (a) 1100 V, 0.5A, 55W on primary, secondary being open circuit.

   (b) 10v, 80A, 400W on low voltage side, HV short circuited.

Given data:

Primary voltage V_1= 1100V, Secondary voltage V_2= 220V

Solution:

O.C test:

Primary voltage V_1= 1100V   No-load input current I_o= 0.5 A

No-load input Power $P_o = 55w$

$$P_o = V_1 I_o \cos\Phi_o$$

No-load input power factor $\cos\Phi_o = \frac{P_o}{V_1 I_o} = \frac{55}{(1100\times0.5)} = 0.1$

$$\cos\Phi_o = 0.1$$

$$\sin\Phi_o = 0.9949$$

Wattfull component (working component)

$$I_w = I_o \cos\Phi_o = 0.5 \times 0.1 = 0.05\ A$$

Wattless component (magnetizing component)

$$I_m = I_o \sin\Phi_o = 0.5 \times 0.9949 = 0.4974$$

Resistance representing the core loss

$$R_o = \frac{V_1}{I_w} = \frac{1100}{0.05} = 22000\ \Omega$$

Magnetizing reactance

$$X_o = \frac{V_1}{Im} = \frac{1100}{0.4974} = 2211.499\ \Omega$$

S.C test:

Short circuit voltage $V_{sc} = 10V$ Short circuit current $I_{sc} = 80\ A$

Losses $W_{sc} = 400\ W$

Impedance of transformer referred to secondary

$$Z_{02} = \frac{V_{sc}}{I_{sc}} = \frac{10}{80} = 0.125\ \Omega$$

$$R_{02} = \frac{W_{sc}}{{I_{sc}}^2} = \frac{400}{80^2} = 0.0625\ \Omega$$

$$X_{02} = \sqrt{{Z_{02}}^2 - {R_{02}}^2} = \sqrt{(0.125^2 - 0.0625^2)} = 0.1082\ \Omega$$

Transformation ratio $K = \frac{V_2}{V_1} = \frac{220}{1100} = 0.2$

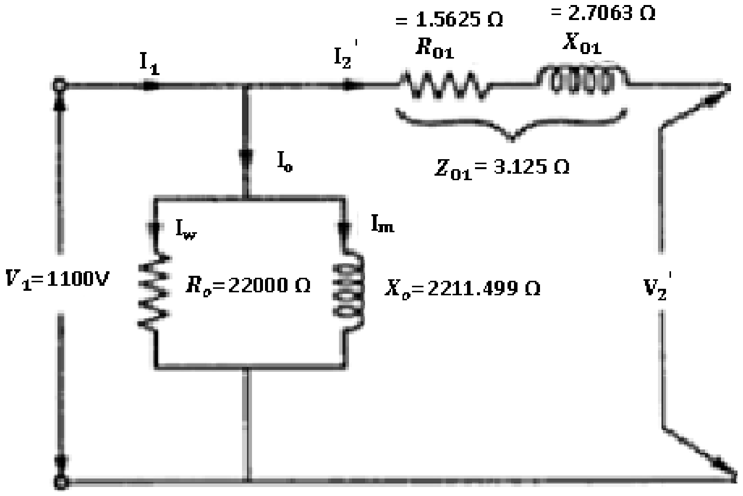
Parameters referred to 1100 V (H.V) side

$$Z_{01} = \frac{Z_{02}}{K^2} = \frac{0.125}{0.2^2} = 3.125\ \Omega$$

$$R_{01} = \frac{R_{02}}{K^2} = \frac{0.0625}{0.2^2} = 1.5625\ \Omega$$

$$X_{01} = \sqrt{{Z_{01}}^2 - {R_{01}}^2} = \sqrt{(3.125^2 - 1.5625^2)} = 2.7063\ \Omega$$

Equivalent circuit is shown below (referred to primary)



8. *Problem 2:* **In a 50 KVA Transformer, the iron loss is 500 W and full load copper loss is 800 W. Find the efficiency at full and half loads at 0.8 p.f. lagging.**

Given data:

Transformer rating = 50KVA, Iron loss P_i= 500w,

Full load copper loss P_{cu} = 800w

Power factor cos Φ = 0.8

To find:

Efficiency at (i) Full load (ii) At half load

Solution:

(i) At full load:

$$\text{Efficiency} = \frac{(n)\text{KVA Cos}\Phi}{(n)\text{KVA Cos}\Phi + P_i + (n)^2\, P_{cu}} \times 100$$

$$= \frac{50\times10^3\times0.8}{(50\times10^3\times0.8)+500+800} \times100$$

$$= 96.85\%$$

(ii) At half load:

$$\text{Efficiency} = \frac{(n)\text{KVA Cos}\Phi}{(n)\text{KVA Cos}\Phi + P_i + (n)^2\, P_{cu}} \times 100$$

$$= \frac{\left(\frac{1}{2}\right)50\times10^3\times0.8}{\left(\frac{1}{2}\right)(50\times10^3\times0.8)+500+\left(\frac{1}{2}\right)^2 800} \times100$$

$$= 96.61\%$$

9. Derive the efficiency of a transformer

Due to losses in a transformer, the output power of a transformer is less than the input power supplied.

Power output = Power input – Total losses

Power input = Power output + Total losses

= Power output + $P_i + P_{cu}$

The efficiency of any device is defined as the ratio of the power output to power input. So for a transformer the efficiency can be expressed as,

$$\eta = \frac{\text{Power output}}{\text{Power input}}$$

$$\eta = \frac{\text{Power output}}{\text{Power output} + P_i + P_{cu}}$$

Now power output = $V_2 I_2 \cos\Phi$

Where Cos Φ = Load power factor

The transformer supplies full load of current I_2 and with termainal voltage V_2.

P_{cu}= Copper loss on full load = ${I_2}^2 R_{2e}$

$$\eta = \frac{V_2 I_2 \cos\Phi}{V_2 I_2 \cos\Phi + P_i + {I_2}^2 R_{2e}}$$

But $V_2 I_2$ = VA rating of a transformer

$$\eta = \frac{(\text{VA rating})\times\cos\Phi}{(\text{VA rating})\times\cos\Phi + P_i + {I_2}^2 R_{2e}}$$

This is the full load percentage efficiency with,

I_2= Full load secondary current

But if the transformer is subjected to fractional load then based on the appropriate values of various quantities, the efficiency can be obtained.

Let n = Fraction by which load is less than full load = $\frac{Actual\ load}{Full\ load}$

For example, if transformer is subjected to half load then,

$$n = \frac{Half\ load}{Full\ load} = \frac{(1/2)}{1} = 0.5$$

When load changes, the load current changes by same proportion as

New I_2= n (I_2) F.L

Similarly the output $V_2 I_2$ cos Φ also reduces by the same fraction. Thus fraction of VA rating is available at the output. Similarly as copper losses are proportional to square of current then,

New $P_{cu} = n^2 (P_{cu})$ F.L.

So copper losses get reduced by n^2.

In general for fractional load, the efficiency is given by,

$$\%\eta = \frac{n(\text{VA rating})\times\cos\Phi}{n(\text{VA rating})\times\cos\Phi + P_i + n^2(P_{cu})\text{F.L}}$$

Where n = *Fraction by which load is less than full load*

For all types of load power factors lagging, leading and unity the efficiency expression does not change, and remains same.

10. Derive the condition for maximum efficiency and explain about the All day efficiency of a transformer

To determine at which load the efficiency will be maximum

Differentiate the denominator with respect to load current I_2 and equate to zero, thus

$$\frac{d}{dI_2}\left[V_2\cos\phi_2+\frac{P_i}{I_2}+I_2R_{02}\right]=0$$

$$-\frac{P_i}{{I_2}^2}+R_{02}=0$$

$$-\frac{P_i}{{I_2}^2}=-R_{02}$$

$$P_i={I_2}^2R_{02}$$

Core loss= copper loss

Thus the efficiency of a transformer is maximum at that load which makes copper loss equal to core loss. Constant losses= variable losses

ALL DAY EFFICIENCY

For a transformer, the efficiency is defined as the ratio of output power to input power. This is its power efficiency. But power efficiency is not the true measure of the performance of some special types of transformers such as distribution transformers. Distribution transformers serve residential and commercial loads. The load on such transformers vary considerably during the period of the day. The primary of the transformers is energized at its rated voltage for 24 hours, to provide continuous supply to the consumer. The core loss which depends on voltage, continuously for all the loads. But copper loss depends on the load condition. For no load, copper loss is negligibly small while on full load it is at its rated value. Hence power efficiency cannot give the measure of true efficiency of such transformers. In such case, the energy output is calculated in kilowatt hours (kWh). Then the ratio of total energy output to total energy input (output+losses) is calculated. Such ratio is called energy efficiency or all day efficiency of a transformer. Based on this efficiency,

$$\boxed{\begin{aligned}\%\text{ All day }\eta &= \frac{\text{Output energy in kWh during a day}}{\text{Input energy in kWh during a day}}\times 100\\ &= \frac{\text{Output energy in kWh during a day}}{\text{Output energy + Energy spent for total losses}}\times 100\end{aligned}}$$

While calculating energies, all energies can be expressed in watt hour (Wh) instead of kilo watt hour (kWh).

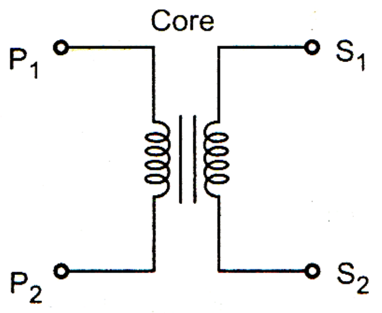
11. Write short notes on autotransformer

Transformers are discussed in which the windings are electrically isolated and the e.m.f. in secondary gets induced due to induction. In practice it is possible to use only one winding for the transformer so that part of this winding is common to the primary and secondary. Such a special type of transformer having only one winding such that part of the winding is common to the primary and secondary is called autotransformer. Obviously the two windings are electrically connected and it works on the principle of conduction as well as induction. Such an autotransformer is very much economical where the voltage ratio is less than 2 and the electrical isolation of the two windings is not necessary. The power transfer in 2 winding transformer is fully inductively while in autotransformer the power is transferred from primary to secondary by both inductively as well as conductively.

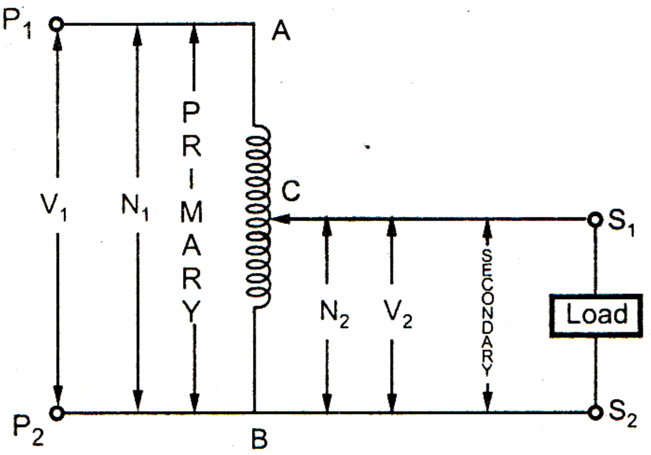
(i) Construction

In an autotransformer only one winding is wound on a laminated magnetic core while in 2 winding transformer, two windings are wound. The single winding of the autotransformer is used as primary and secondary. The part of the winding is common to both primary and secondary. The voltage can be stepped down or stepped up using an autotransformer. Accordingly the autotransformers are classified as step-up autotransformer and step-down autotransformer.

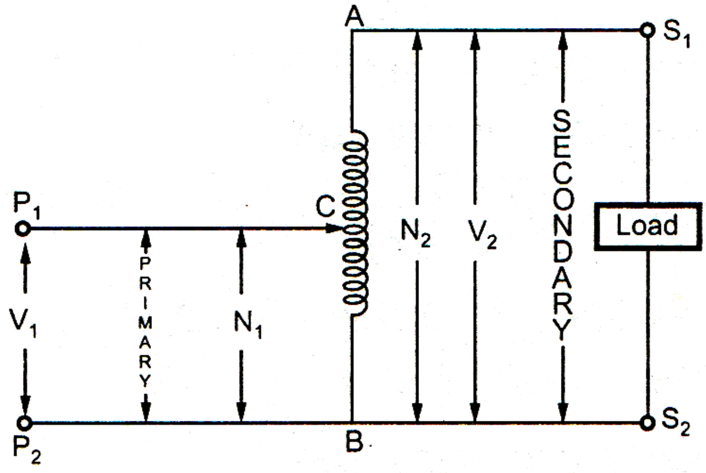
The Fig. a shows the conventional two winding transformer while the Fig. b and c show the step down and step up autotransformers respectively.



(a) 2 winding transformer



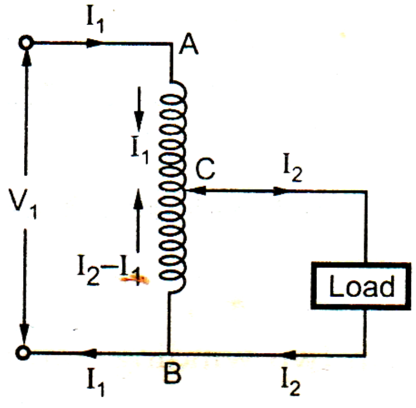
(b) step-down autotransformer



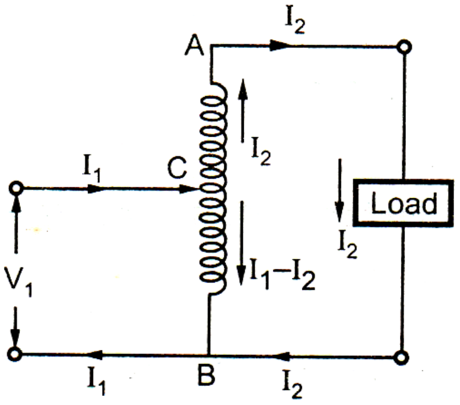
(c) Step up autotransformer

In step down autotransformer shown in the Fig. b, the entire winding acts as a primary while the part of the Winding is used common to both primary and secondary. Thus AB forms the primary having N1 turns while BC forms the secondary with N2 turns. As $N_2 < N_1$, the output voltage $V_2 < V_1$ and it acts as a step-down auto transformer. In step-up autotransformer shown in the Fig. c, the entire winding acts as secondary while the part of the winding is used common to both primary and secondary. Thus AB forms the secondary having N_2 turns while BC forms the primary with N_1 turns. As $N_2 > N_1$, the output voltage $V_2 > V_1$ and it acts as a step-up autotransformer.

The current distribution in the step down and step up autotransformers is shown in the Fig. d and e respectively.



(d) step-down autotransformer



(e) step up autotransformer

(ii) Transformation Ratio of An Autotransformer

Neglecting the losses, the leakage reactance and the magnetising current, the transformation ratio of an autotransformer can be obtained as,

$$K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

K is greater than unity for step-up autotransformer while K is less than unity for step down autotransformer. `

Due to the use of single winding, compared to the normal two winding transformer, for the same capacity and voltage ratio, there is substantial saving in copper in case of autotransformers.

Let us obtain the expression for the copper saving in the autotransformers.

(iii)Copper Saving in Autotransformer

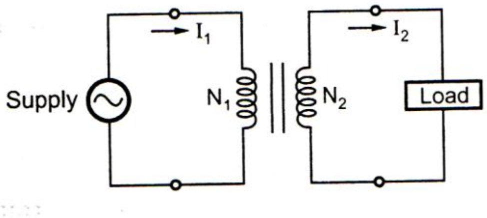
For any winding, the cross-section of winding is proportional to the current I. While the total length of the winding is proportional to the number of turns N. Hence the weight of copper is proportional to the product of N and I.

Weight of copper α NI

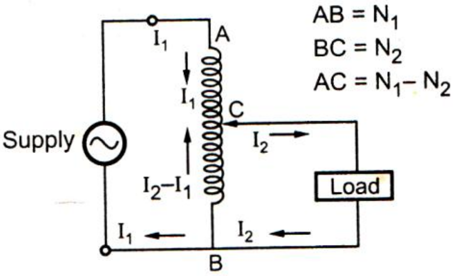
Where I = current in the winding

and N = number of turns of the winding

Consider a two winding transformer and step-down autotransformer as shown in Fig. f and g.



(f) Two winding transformer



(g) Step down transformer

Let W_{TW} = total weight of copper in two winding transformer

W_{AT} = weight of copper in autotransformer

In two winding transformer,

Weight of copper of primary α $N_1 I_1$

Weight of copper of secondary α $N_2 I_2$

W_{TW} α $N_1I_1 + N_2 I_2$ ….. total weight of Cu

In case of step-down autotransformer.

Weight of copper of section AC α $(N_1 - N_2) I_1$

Weight of copper of section BC α $N_2 (I_2 - I_1)$

W_{AT} α $(N_1 - N_2) I_1 + N_2 (I_2 - I_1)$ …..total weight of Cu

Taking ratio of the two Weights,

$$\frac{W_{TW}}{W_{AT}} = \frac{N_1I_1+N_2I_2}{(N_1-N_2)I_1+N_2(I_2-I_1)}$$

$$= \frac{N_1I_1+N_2I_2}{N_1I_1- N_2I_1+N_2I_2-N_2I_1}$$

$$=\frac{N_1I_1+N_2I_2}{N_1I_1+N_2I_2-2N_2I_1}$$

But $K = \frac{N_2}{N_1} = \frac{I_1}{I_2}$

$$\frac{W_{TW}}{W_{AT}} = \frac{N_1I_1+KN_1(\frac{I_1}{K})}{N_1I_1+KN_1(\frac{I_1}{K})-2KN_1I_1}$$

$$= \frac{2N_1I_1}{2N_1I_1-2kN_1I_1} = \frac{1}{1-K}$$

$$W_{AT} = (1-K) W_{TW}$$

Saving of copper $= W_{TW} - W_{AT} = W_{TW} - (1-K) W_{TW}$

Saving of copper $= K W_{TW}$ ….. For step down autotransformer

Thus saving of copper is K times the total weight of copper in two winding transformer.

And Saving of copper $= \frac{1}{K} W_{TW}$ ….. For step up autotransformer

12. Discuss the constructional details and various connections, operation of three phase transformer

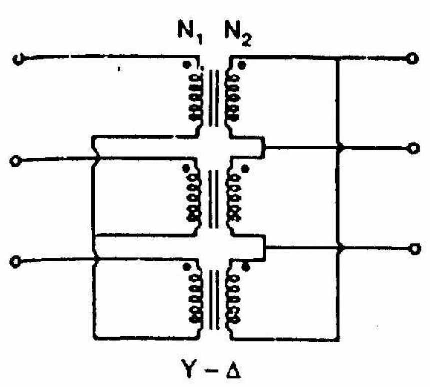
THREE-PHASE TRANSFORMER

Three phase voltages are raised or lowered by means of three-phase transformers. A three-phase transformer can be built in two ways viz., (i) by suitably connecting a bank of three single-phase transformers or (ii) by constructing a three-phase transformer on a common magnetic structure. In either case, the windings may be connected in Y – Y, Δ – Δ, Y – Δ or Δ – Y.

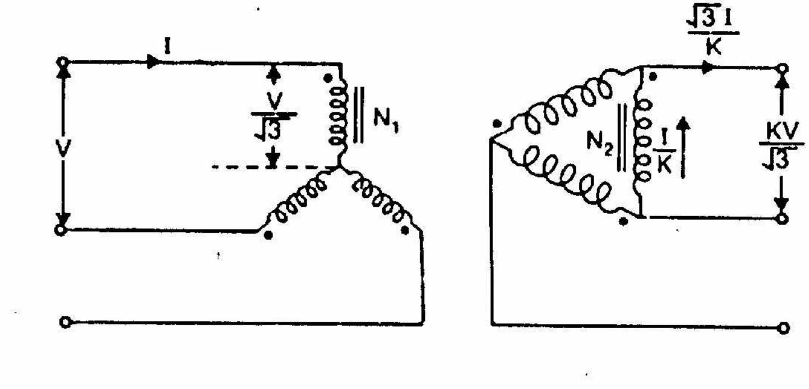
(i) BANK OF THREE SINGLE-PHASE TRANSFORMERS

Three similar single-phase transformers can be connected to form a three-phase transformer. The primary and secondary windings may be connected in star (Y) or delta (Δ) arrangement. The below Figure (i) shows a Y - Δ connection of a three phase transformer. The primary windings are connected in star and the secondary windings are connected in delta. A more convenient way of showing this connection is illustrated in the below figure (ii) The ratio of secondary phase voltage to primary phase voltage is the phase transformation ratio K.

Phase transformation ratio, $K = \frac{\text{Secondary phase voltage}}{\text{Primary phase voltage}} = \frac{N_2}{N_1} = \frac{I_{P1}}{I_{P2}}$



(i)



(ii)

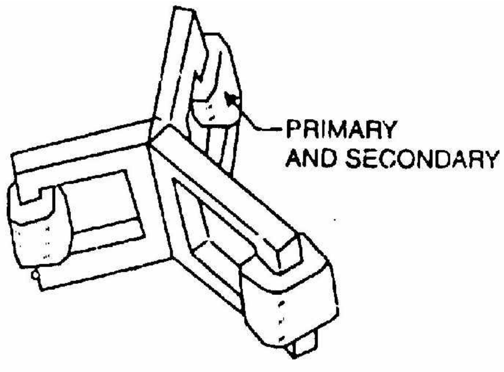
Referring to the above figure (ii), primary line-to-line voltage is V and the primary line current is I. The phase transformation ratio is K (= N_2/N_1). The secondary line voltage and line current are also shown in the above figure.

(ii) THREE-PHASE TRANSFORMER

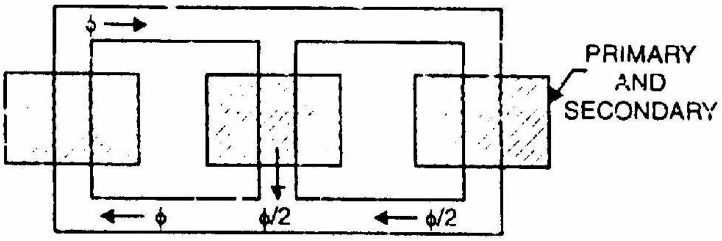
A three-phase transformer can be constructed by having three primary and three secondary windings on a common magnetic circuit. The basic principle of a three phase transformer is illustrated in figure (i) The three single-phase core type transformers, each with windings (primary and secondary) on only one leg have their unwound legs combined to provide a path for the returning flux.

The primaries as well as secondary may be connected in star or delta. If the primary is energized from a 3-phase supply, the central limb (i.e., unwound limb) carries the fluxes produced by the 3-phase primary windings. Since the phasor sum of three primary currents at any instant is zero, the sum of three fluxes passing through the central limb must be zero. Hence no flux exists in the central limb and it may, therefore, be eliminated.

This modification gives a three leg core type 3-phase transformer. In this case, any two legs will act as a return path for the flux in the third leg. For example, if flux is ϕ in one leg at some instant, then flux is ϕ /2 in the opposite direction through the other two legs at the same instant. All the connections of a 3-phase transformer are made inside the case and for delta-connected winding three leads are brought out while for star connected winding four leads are brought out.



(*i*)



(*ii*)

For the same capacity, a 3-phase transformer weighs less, occupies less space and costs about 20% less than a bank of three single-phase transformers.

Because of these advantages, 3-phase transformers are in common use, especially for large power transformations.

A disadvantage of the three-phase transformer lies in the fact that when one phase becomes defective, the entire three-phase unit must be removed from service. When one transformer in a bank of three single-phase transformers becomes defective, it may be removed from service and the other two transformers may be reconnected to supply service on an emergency basis until repairs can be made.

(iii) THREE-PHASE TRANSFORMER CONNECTIONS

A three-phase transformer can be built by suitably connecting a bank of three single-phase transformers or by one three-phase transformer. The primary or secondary windings may be connected in either star (Y) or delta (Δ) arrangement. The four most common connections are (i) Y-Y (ii) Δ-Δ (iii) Y-Δ and (iv) Δ-Y.

$$K = \frac{\text{Secondary phase voltage}}{\text{Primary phase voltage}} = \frac{V_{Ph2}}{V_{Ph1}} = \frac{N_2}{N_1}$$

Reference:

- *B. L. Theraja & A. K. Theraja, A Textbook of Electrical Technology: AC and DC Machines, Volume - II, 23rd Edition, S. Chand & Company, New Delhi, 2012*
- *U. A. Bakshi, M. V. Bakshi, Electrical Machines-I, Second Edition, Technical Publications*

2. AC MACHINES

Theory and operation of 3 phase Induction motor - constructional details – starting methods – speed control methods – principle of operation of single phase Induction motor – stepper motor – AC series motor – Applications

Part-A (2 Marks)

1. What is the function of capacitor in a single phase induction motor (NOV/2014)
   - Developing high starting torque
   - To improve the power factor
2. What are the classifications of three phase induction motor based on the method of construction (NOV/2014)

   The three phase induction motor are classified based on their constructions are
   - Squirrel cage induction motor
   - Slip ring (or) wound rotor induction motor
3. What is Slip? (APRIL/2014)

   (or)

   Define slip of an induction motor. (APRIL/2012)

   Slip of the induction motor is defined as the ***"Difference between the synchronous speed (Ns) and actual speed of rotor i.e. motor (N) expressed as a friction of the synchronous speed (Ns)"***. This is also called **absolute slip or fractional slip** and is denoted as's'

   Thus $\boldsymbol{s = \frac{Ns-N}{Ns}}$-- Absolute slip

   The percentage slip is expressed as,

   $\% \boldsymbol{s = \frac{Ns-N}{Ns} * 100}$----------------------------------- Percentage slip
4. Mention the methods available to make single phase induction motors self-starting (APRIL/2014)

   (or)

   What are the classifications of single phase induction motor based on the method of starting(NOV/2012)

   (Or)

   What are the different types of single phase induction motor? (APRIL/2012)

- Split phase induction motor
- Capacitor start induction motor
- Capacitor start and capacitor run induction motor
- Shaded pole induction motor

5. A 6 pole, 50 Hz, three phase induction motor runs at 800 rpm at full load. Determine the value of slip at this load condition. (NOV/2013)

P= 6
F= 50 Hz
N= 800 rpm

$$N_S = \frac{120\,f}{\mathrm{P}}$$

$$N_S = \frac{120 * 50}{6} = 1000\ rpm$$

$$\%\ s = \frac{Ns - N}{Ns} * 100$$

$$\%\ s = \frac{1000 - 800}{1000} * 100$$

$$\%\ s = 20\ \%$$

6. Mention some applications of AC series motor (NOV/2013)
   - Electric traction
   - Hoists
   - Locomotives
7. What are the advantages of three phase induction motor? (APRIL/2013)
   - Simple and Rugged construction
   - High efficiency
   - Self-starting motor
   - Good power factor
   - High reliable
   - Requires less maintenance
   - Low cost
   - Can be operated in explosive and in dirty environment
8. Mention the types of stepper motor. (APRIL/2013)
   - Variable reluctance stepper motor
   - Permanent magnet stepper motor
   - Hybrid stepper motor
9. Compare squirrel cage rotor and slip ring rotor. (NOV/2012)

S. NO.	**SLIP RING INDUCTION ROTOR**	**SQUIRREL CAGE ROTOR**
1	Rotor consists of three windings similar to stator winding	Rotor consists of bars which are shorted at the ends with the help of end rings
2	Construction is complicated	Construction is simple
3	Resistance can be added externally	Resistance cannot be added externally
4	Slip rings and brushes are present to add external resistance	Slip rings and brushes are absent
5	The construction is delicate and due to brushes, frequent maintenance is necessary	The construction is robust and maintenance free

6	The rotors are very costly	Rotor is cheap
7	Only 5% of induction motors in industry use slip ring rotor	Very commonly used motor in industry
8	High starting torque can be obtained	Moderate starting torque can be obtained
9	Speed control is possible	Speed control is not possible as it has short circuit rotor
10	Less efficiency	High efficiency

10. What are the main parts of an induction motor

- Stator (Stationary parts)
- Rotor (Rotating parts)

(Part- B) 11 Marks

1. With neat sketches explain the constructional details and operation of three phase induction motor. (APRIL/2013)

(or)

Explain the construction of an three phase induction motor with neat sketch**.**

CONSTRUCTION OF THREE PHASE INDUCTION MOTOR

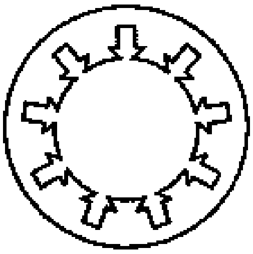
Basically the induction motor (all motors) consists of two main parts, namely

- STATOR
- ROTOR

The conversion of electrical power to mechanical power takes place in a rotor. Hence rotor develops a driving torque and rotates.

STATOR:

The stator has a laminated type of construction made up of stampings which are 0.4 to 0.5 mm thick. The stampings are slotted in inner periphery to carry the stator winding. The stampings are insulated from each other. Such a construction essentially keeps the iron losses to a minimum value. The number of stampings are stamped together to build the stator core. The built up core is then fitted in a casted or fabricated steel frame. The choice of material for the stampings is generally silicon steel, which minimizes the hysteresis loss. The slots in the periphery of the stator core carries a three phases winding, connected either in star or delta. This three phase winding is called stator winding. It is wound for definite number of poles. This winding when excited by a three phase supply produces a magnetic rotating field as discussed earlier. The choice of number of poles depends on the speed of the rotating magnetic field required. The radial ducts are provided for the cooling purpose. In some cases, all the six terminals of three phase stator winding are brought out which gives flexibility to the user to connect them either in star or delta.



Stator core

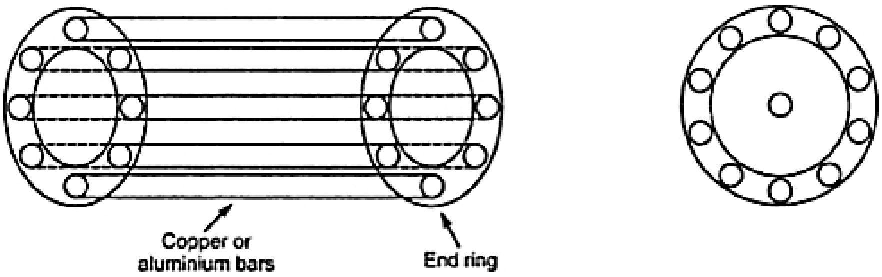
ROTOR:

The rotor is placed inside the stator. The rotor core is also laminated in construction and uses cast iron. It is cylindrical, with slots on its outer periphery. The rotor conductors or winding is placed in the rotor slots. The two type of rotor constructions which are used for induction motors are,

- Squirrel cage rotor and
- Slip ring wound rotor

Squirrel Cage Rotor

The rotor core is cylindrical and slotted on its periphery. The rotor consists of un-insulated copper or aluminum bars called **rotor conductors**. The bars are placed in the slots. These bars are permanently shorted at each end with the help of conducting copper ring called **end ring**. The bars are usually brazed to the end rings to provide good mechanical strength. The entire structure looks like a cage, forming a closed electrical circuit. So the rotor is called squirrel cage rotor. The construction is shown in the below figures.

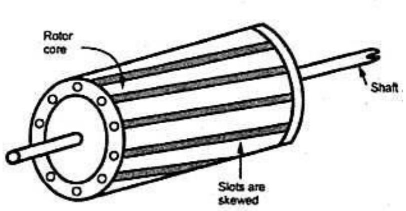


(a) Cage type structure of rotor **(b) Symbolic representation**

Squirrel cage rotor

As the bars are permanently shorted to each other through end ring, the entire rotor resistance is very small. Hence this rotor is also called **short circuited rotor**. As rotor itself is short circuited, no external resistance can have any effect on the rotor resistance. Hence no external resistance can be introduced in the rotor circuit. So slip ring and brush assembly is not required for this rotor. Hence the construction of this rotor is very simple. The air gap between stator and rotor is kept uniform and as small as possible.

In this type of rotor, the slots are not arranged parallel to the shaft axis but are skewed as shown in the below figure.



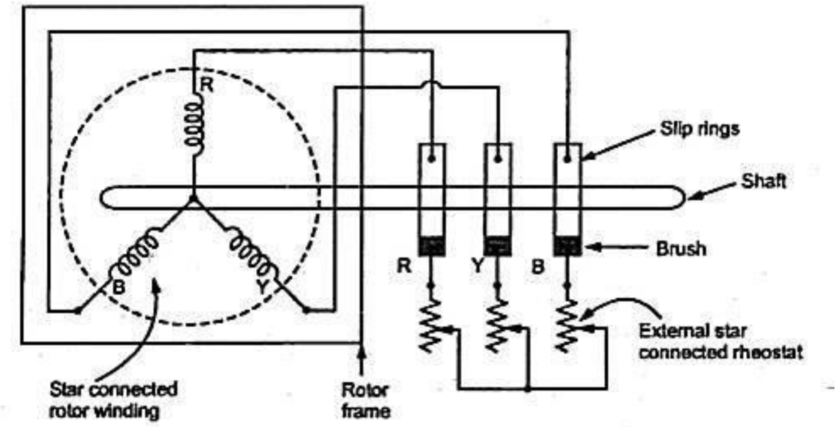
Skewing in rotor construction

The skewing is done in the squirrel cage rotor to

- Reduce humming noise hence skewing makes the motor operation quite.
- Make the rotor operation smooth.
- Avoid magnetic locking between stator and rotor teeth
- Increases the effective transformation ratio between stator and rotor.

Slip Ring Rotor or Wound Rotor

In this type of construction, rotor winding is exactly similar to the stator. The rotor carries a three phase star or delta connected, distributed winding, wound for same number of poles as that of stator. The rotor construction is laminated and slotted. The slots contain the rotor winding. The three ends of three phase winding, available after connecting the winding in star or delta, are permanently connected to the slip rings. The slip rings are mounted on the same shaft. We have seen that slip rings are used to connect external stationary circuit to the internal rotating circuit. So in this type of rotor, the external resistances can be added with the help of brushes and slip ring arrangement, in series with each phase of the rotor winding.


R
Y
B
Slip rings
Shaft
Brush
R
Y
B
External star connected rheostat
Star connected rotor winding
Rotor frame

Slip rings or wound rotor construction

In the running condition, the slip rings are shorted. This is possible by connecting a metal collar which gets pushed and connects all the slip rings together, shorting them. At the same time brushes are also lifted from the slip rings. This avoids wear and tear of the brushes due to friction. The possibility of addition of an external resistance in series with the rotor, with the help of slip sings is the main feature of this type of rotor.

WORKING PRINCIPLE OF THREE PHASE INDUCTION MOTOR

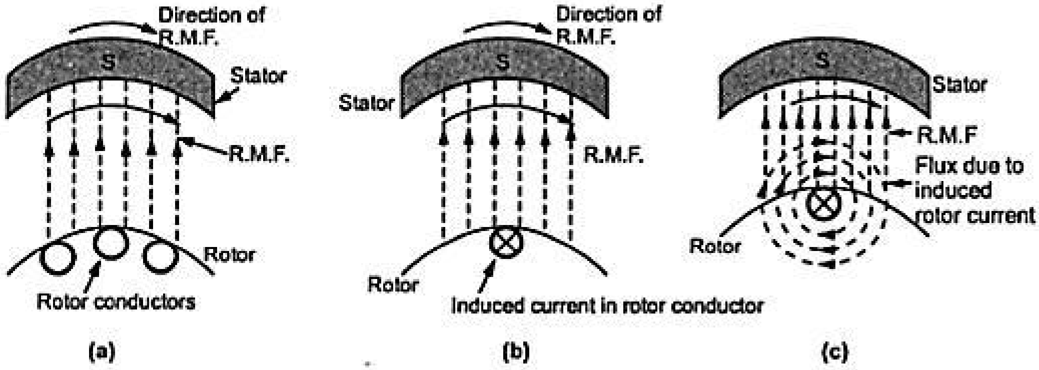
Induction motor works on the principle of Faradays Law of Electromagnetic induction. When a three phase supply is given to the three phase stator winding, a rotating magnetic field of constant magnitude will be produced. The speed of this rotation magnetic field is synchronous speed N_S r.p.m.

Ns=120f/P

Where, f = supply frequency.

P = Number of poles for which stator winding is wound.

This rotating field produces an effect of rotating poles around a rotor. Let direction of rotation of this rotating magnetic field is clockwise as shown in the below figure (a).



Now at this instant rotor is stationary and stator flux R.M.F. is rotating. So it's obvious that there exists a relative motion between the R.M.F. and rotor conductors. Now the R.M.F. gets cut by rotor conductors as R.M.F. sweeps over rotor conductors. Whenever conductor cuts the flux, e.m.f. gets induced in it. So e.m.f. gets induced in the rotor conductors called rotor induced e.m.f. This is electro- magnetic induction. As rotor forms closed circuit, induced e.m.f. circulates current through rotor called rotor current as shown in the above figure (b).

Any current carrying conductor produces its own flux. So rotor produces its flux called rotor flux. For assumed direction of rotor current, the direction of rotor flux is clockwise as shown in the above figure (c). This direction can be easily determined using right hand thumb rule. Now there are two fluxes, one R.M.F. and other rotor flux. Both the fluxes interact with each as shown in the below figure (d). On left of rotor conductor, two fluxes cancel each other to produce low flux area. As flux lines act as stretched rubber band, high flux density area exerts a push on rotor conductor towards low flux density area. So rotor conductor experiences a force from left to right in this case, as shown in the below figure (d), due to interaction of the two fluxes.

As all the rotor conductors experience a force, the overall rotor experiences a torque and starts rotating. So interaction of the two fluxes is very essential for a motoring action. Hence rotor starts rotating in the same direction as that of rotating magnetic field.

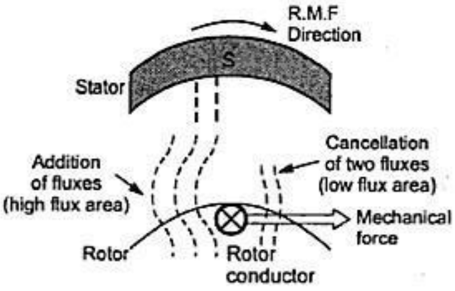


Figure (d)

SLIP OF INDUCTION MOTOR

When the rotor rotates in the same direction as that of R.M.F. but in steady state attains a speed less than the synchronous speed. The difference between the two speeds i.e. synchronous speed of R.M.F. (Ns) and rotor speed (N) is called **slip speed**. This slip speed is generally expressed as the percentage of the synchronous speed.

So slip of the induction motor is defined as the ***"Difference between the synchronous speed (Ns) and actual speed of rotor i.e. motor (N) expressed as a friction of the synchronous speed (Ns)"***. This is also called **absolute slip or fractional slip** and is denoted as 's'

Thus

$s = \frac{Ns-N}{Ns}$ -- Absolute slip

The percentage slip is expressed as,

$\% s = \frac{Ns-N}{Ns} * 100$ ----------------------------------- Percentage slip

In terms of slip, the actual speed of motor (N) can be expressed as,

At

$$N = Ns(1 - s)$$

$s = 1$ ---------------------------------- At start

At start, motor is at rest and hence its speed N is zero.

This is maximum value of slip s possible for induction motor which occurs at start. While s = 0 given us N = Ns which is not possible for an induction motor. So slip of induction motor cannot be zero under any circumstances. Practically motor operates in the slip range of 0.01 to 0.05 i.e. 1 % to 5 %. The slip corresponding to full load speed of the motor is called full load slip.

2. Derive the equation for torque developed by three phase induction motor. Draw the torque slip curve and deduce the condition for maximum torque (11) (NOV/2014)

TORQUE EQUATION:

"Torque is the turning force through a radius and the units is rated in Nm"

The torque produced in the induction motor depends on the following factors:

- The part of rotating magnetic field which reacts with rotor and is responsible to produce induced e.m.f. in rotor.
- The magnitude of rotor current in running condition.
- The power factor of the rotor circuit in running condition.

Mathematically the relationship can be expressed as

$\mathbf{T \alpha \Phi I_{2r} \cos \Phi_{2r}}$ ----------- (1)

Where, Φ = Flux responsible to produce induced e.m.f.

I_{2r} = Rotor running condition

Cos Φ_{2r} = Running p.f. of motor

The flux Φ produced by stator is proportional to stator voltage.

$$\Phi \propto E_1 \quad \text{----------- (2)}$$

While E_1 and E_2 are related to each other through ratio of stator turns to rotor turns i.e. K

$$\frac{E_2}{E_1} = K \quad \text{------------ (3)}$$

Using equation (3) in (2) we can write,

$$E_2 \propto \Phi \quad \text{------------- (4)}$$

Thus in equation (1), ϕ can be replaced by E_2

While $$I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{s\,E_{2r}}{\sqrt{R_2^2+(sX_2)^2}} \quad \text{----------- (5)}$$

And $$\cos\phi_{2r} = \frac{R_2}{Z_{2r}} = \frac{R_2}{\sqrt{R_2^2+(sX_2)^2}} \quad \text{---------- (6)}$$

Using (4), (5), (6) in equation (1),

$$T \propto E_2 \frac{s\,E_{2r}}{\sqrt{R_2^2+(sX_2)^2}} \frac{R_2}{\sqrt{R_2^2+(sX_2)^2}}$$

$$\boxed{T \propto \frac{s\,E_2^2\,R_2}{R_2^2+(sX_2)^2}} \text{N-m}$$

$$T = \frac{k\,s\,E_2^2\,R_2}{R_2^2+(sX_2)^2} \quad \text{------------ (7)}$$

Where, k = *Constant of proportionality*

The constant k is proved to be $3/2\pi n_s$ for the three phase induction motor

$$k = \frac{3}{2\pi n_s} \quad \text{---------------- (8)}$$

n_S = synchronous speed in r.p.s. = $\frac{N_s}{60}$

Using (8) in (7) we get the torque equation as,

$$\boxed{T = \frac{3}{2\pi n_s}\frac{s\,E_2^2\,R_2}{R_2^2+(sX_2)^2}} \text{N-m}$$

So torque developed at any load condition can be obtained if slip at that load is known and all standstill rotor parameters are known.

STARTING TORQUE

Starting torque is nothing but the torque produced by an induction motor as start. At start, N= 0 and slip s = 1. So putting s = 1 in the torque equation we can write expression for the starting torque T_{st} as,

$$T_{st} = \frac{3}{2\pi n_s} * \frac{E_2^2 R_2}{R_2^2 + X_2^2}\ N-m$$

The change in R_2 at start is possible in case of slip ring induction motor only. This is the principle used in case of slip induction motor to control the starting torque T_{st}.

CONDITION OF MAXIMUM TORQUE

It is clear that torque depends on slip at which motor is running. The supply voltage to the motor is usually rated and constant and there exists a fixed ratio between E_1 and E_2. Hence E_2 is also constant. Similarly R_2, X_2 and n_s are constants for the induction motor. Hence while finding the condition for maximum torque, remember that the only parameter which controls the torque is slip s.

$$\frac{dT}{ds} = 0$$

where $$T = \frac{k s E_2^2 R_2}{R_2^2 + (sX_2)^2}$$

While carrying out differentiation remember that E_2, R_2, X_2 and k are constants. The only variable is slip s. As load on motor changes, its speed changes and hence slip changes. This slip decides the torque produced corresponding to the load demand.

$$T = \frac{k s E_2^2 R_2}{R_2^2 + s^2 X_2^2} \qquad \text{... writing } (s\,X_2)^2 = s^2 X_2^2$$

As both numerator and denominator contains s terms, differentiate T with respect to s using the rule of differentiation for u/v.

$$\therefore \frac{dT}{ds} = \frac{(k s E_2^2 R_2) \frac{d}{ds} (R_2^2 + s^2 X_2^2) - (R_2^2 + s^2 X_2^2) \frac{d}{ds} (k s E_2^2 R_2)}{(R_2^2 + s^2 X_2^2)^2} = 0$$

$$\therefore \quad k\, s\, E_2^2\, R_2\, [2s\, X_2^2] - (R_2^2 + s^2 X_2^2)\,(k\, E_2^2\, R_2) = 0$$

$$\therefore 2\, s^2\, k\, X_2^2\, E_2^2\, R_2 - R_2^2\, k\, E_2^2\, R_2 - k\, s^2\, X_2^2\, E_2^2\, R_2 = 0$$

$$\therefore \quad k\, s^2\, X_2^2 E_2^2\, R_2 - R_2^2\, k X_2^2\, R_2 = 0$$

$$s^2 X_2^2 - R_2^2 = 0 \qquad \text{Taking } k\, E_2^2\, R_2 \text{ common.}$$

$$s^2 = \frac{R_2^2}{X_2^2}$$

$$\boxed{s = \frac{R_2}{X_2} \qquad \text{Neglecting negative slip}}$$

This is the slip at which the torque is maximum and is denoted as s_m.

$$\boxed{s_m = \frac{R_2}{X_2}}$$

It is the ratio of standstill per values of resistance and reactance of rotor, when the torque produced by the induction motor is at its maximum.

MAXIMUM TORQUE:

This can be obtained by substituting $s_m = R_2/X_2$ in the torque equation. It is denoted by T_m.

$$T_m = \frac{k s_m E_2^2 R_2}{R_2^2 + (s_m X_2)^2}$$

$$T_m = \frac{k\left(\frac{R_2}{X_2}\right) E_2^2 R_2}{R_2^2 + \left(\frac{R_2}{X_2} X_2\right)^2}$$

$$\boxed{T_m = \frac{k E_2^2}{2X_2} \text{ N-m}}$$

From the expression of T_m, it can be observed that

- It is inversely proportional to the rotor reactance.
- It is directly proportional to the square of the rotor induced e.m.f. at standstill.

The most interesting observation is, the maximum torque is not dependent on the rotor resistance R_2. But the slip at which it occurs i.e. speed at which it occurs depends on the value of rotor resistance R_2.

3. *Problem 1:* A 3 phase, 400 V, 50 Hz, 4 pole induction motor has star connected stator winding. The rotor resistance and reactance are 0.1 Ω and 1 Ω respectively. The full load speed is 1440 r.p.m. Calculate the torque developed on full load by the motor. Assume stator to rotor ratio as 2:1.

Solution:

The given values are,
$P = 4$, $f = 50$ Hz, $R_2 = 0.1\ \Omega$, $X_2 = 1\ \Omega$, $N = 1440$ r.p.m. Stator turns/Rotor turns = 2/1

$K = E_2 / E_1$ = Rotor turns/Stator turns = 1/2 = 0.5

$N_s = 120f/P = 120 \times 50 / 4 = 1500$ r.p.m.

$E_{1line} = 400$ V

$E_{1ph} = E_{1line} / \sqrt{3} = 400/\sqrt{3} = 230.94$ V

But, $E_{2ph} / E_{1ph} = 0.5 = K$

$E_{2ph} = 0.5 \times 230.94 = 115.47$ V

Full load slip, $s = (N_s - N)/N_s = (1500-1400)/1500 = 0.04$

n_s = Synchronous speed in r.p.s.

$= N_s/60 = 1500/60 = 25$ r.p.s.

$$T = \frac{3}{2\pi n_s} \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

$$T = \frac{3}{2\pi * 25} * \frac{0.04 * (115.47)^2 * 0.1}{(0.1)^2 + (0.04 * 1)^2}$$

T = 87.81 N-m

4. *Problem 2:* A 400 V, 4 pole, 3 phases, and 50 Hz star connected induction motor has a rotor resistance and reactance per phase equal to 0.01 Ω and 0.1 Ω respectively. Determine i) Starting torque ii) slip at which maximum torque will occur iii) speed at which maximum torque will occur. Assume ratio of stator to rotor turns as 4.

Solution:

The given values are,
$P = 4$, $f = 50$ Hz, stator turns/ rotor turns = 4, $R_2 = 0.01\ \Omega$, $X_2 = 0.1\ \Omega$

E_{1line} = stator line voltage = 400 V

$E_{1ph} = E_{1line}/\sqrt{3} = 400/\sqrt{3} = 230.94$ V ....star connection

$K = E_{2ph}/E_{1ph}$ = Rotor turns/ Stator turns = 1/4

$E_2 = (1/4) \times E_{1ph} = 230.94/4 = 57.735$ V

$N_s = 120f/P = 120 \times 50 / 4 = 1500$ r.p.m.

i) At start, $s = 1$

$T_{st} = (k E_2^2 R_2)/ (R_2^2 + (X_2)^2)$ where $k = 3/ (2 \pi n_s)$

$n_s = N_s/60 = 1500/60 = 25$ r.p.s.

$k = 3/ (2\pi \times 25) = 0.01909$

$T_{st} = (0.01909 \times 57.735^2 \times 0.01)/ (0.01^2 + 0.1^2) =$ **63.031 N-m**

ii) Slip at which maximum torque occurs is,

$S_m = R_2/X_2 = 0.01/0.1 = 0.1$

$\% S_m = 0.1 \times 100 =$ **10%**

iii) Speed at which maximum torque occurs is speed corresponding to,

$N = N_S (1 - s_m) = 1500 (1 - 0.1) =$ **1350 r.p.m.**

5. Draw torque slip characteristics curve and explain

TORQUE-SLIP CHARACTERISTICS

As the induction motor is located from no load to full load, its speed decreases hence slip increases. Due to the increased load, motor has to produce more torque to satisfy load demand. The torque ultimately depends on slip. The behaviour of motor can be easily judged by sketching a curve obtained by plotting torque produced against slip of induction motor.

"The curve obtained by plotting torque against slip from s = 1 (at start) to s = 0 (at synchronous speed) is called torque-slip characteristics of the induction motor." We have seen that for a constant supply voltage, E_2 is also constant. So we can write torque equations as,

$$\boxed{T \propto \frac{s R_2}{R_2^2 + (sX_2)^2}}$$

To judge the nature of torque-slip characteristics let us divide the slip range (s = 0 to s = 1) into two regions and analyse them independently.

Low slip region:

In low slip region, 's' is very very small. Due to this, the term $(s X_2)^2$ is so small as compared to R_2^2 that it can be neglected.

$$\boxed{T \propto \frac{s R_2}{R_2^2} \propto s} \qquad \text{... As } R_2 \text{ is constant.}$$

Hence in low slip region torque is directly proportional to slip. So as load increases, speed decreases, increasing the slip. This increases the torque which satisfies the load demand. Hence the graph is straight line in nature. At $N = N_S$, $s = 0$ hence $T = 0$. As no torque is generated at $N = N_S$, motor stops if it tries to achieve the synchronous speed. Torque increases linearly in this region, of low slip values.

High slip region:

In this region, slip is high i.e. slip value is approaching to 1. Here it can be assumed that the term R_2^2 is very very small as compared to $(s X_2)^2$. Hence neglecting from the denominator, we get

$$\boxed{T \propto \frac{s R_2}{(sX_2)^2} \propto \frac{1}{s}} \qquad \text{where } R_2 \text{ and } X_2 \text{ are constants.}$$

So in high slip region torque is inversely proportional to the slip. Hence its nature is like rectangular hyperbola. Now when load increases, load demand increases but speed decreases. As speed decreases, slip increases. In high slip region as $T \alpha 1/s$, torque decreases as slip increases.

But torque must increases to satisfy the load demand. As torque decreases, due to extra loading effect, speed further decreases and slip further increases. Again torque decreases as $T \alpha 1/s$ hence same load acts as an extra load due to reduction in torque produced. Hence speed further drops. Eventually motor comes to standstill condition. The motor cannot continue to rotate at any point in this high slip region. Hence this region is called unstable region of operation.

So torque - slip characteristics has two parts,

- Straight line called stable region of operation
- Rectangular hyperbola called unstable region of operation.

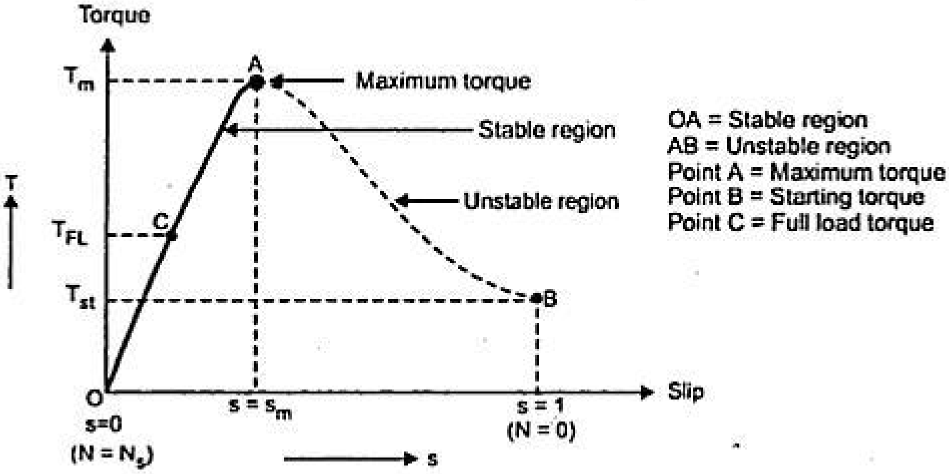
Stable operation:

In low slip region, as load increases, slip increases and torque also increases linearly. Every motor has its own limit to produce a torque. The maximum torque, the motor can produces as load increases is T_m which occurs at $s = s_m$. So linear behavior continues till $s = s_m$. So range $s = 0$ to $s = s_m$ is called **low slip region**, known as stable region of operation. Motor always operates at a point in this region.

Unstable operation:

If load is increased beyond this limit, motor slip acts dominantly pushing motor into high slip region. Due to unstable conditions, motor comes to standstill condition at such a load. Hence i.e. maximum torque which motor can produce is also called ***breakdown torque or pull out torque***. And range $s = s_m$ to $s = 1$ is called high slip region which is rectangular hyperbola, called unstable **region of operation**. Motor cannot continue to rotate at any point in this region. At $s = 1$, $N = 0$ i.e. start, motor produces a torque called **starting torque** denoted as T_{st}.

TORQUE - SLIP CHARACTERISTICS CURVE:



Torque- slip characteristics

When the load on the motor increases, the torque produced increases as speed decreases and slip increases. The increases torque demand is satisfied by drawing motor current from the supply. The load which motor can drive safely while operating continuously and due to such load, the current drawn is also within safe limits is called full load condition of motor. When current increases, due to heat produced the temperature rise. The safe limit of current is that which when drawn for continuous operation of motor, produces a temperature rise well within the limits. Such a full load point is shown on the torque-slip characteristics torque as $T_{F.L}$.

The interesting thing is that the load on the motor can be increased beyond point C till maximum torque condition. But due to high current and hence high temperature rise there is possibility of damage of winding insulation, if motor is operated for longer time duration in this region i.e. from point C to B. But motor can be used to drive loads more than full load, producing torque upto maximum torque for short duration of time. Generally full load torque is less than the maximum torque.

So region OC upto full load condition allows motor operation continuously and safely from the temperature point of view. While region CB is possible to achieve in practice but only for short duration of time and not for continuous operation of motor. This is the difference between full load torque and the maximum or breakdown torque. The breakdown torque is also called **stalling torque**.

6. Explain in detail about the losses and efficiency of an three phase induction motor

LOSSES IN INDUCTION MOTOR:

The various power losses in an induction motor can be classified as,

- ***Constant losses***
- ***Variable losses***

Constant losses:

Constant losses in three phase induction motor can be further classified as

- Core losses
- Mechanical losses.

Core losses:

Core losses occur in stator core and rotor core. These are also called **iron losses** as the stator and rotor core are made up of iron material (Silicon steel). These losses sub divided into

- Eddy current losses
- Hysteresis losses

The eddy current losses are minimized by using laminated construction while hysteresis losses are minimized by selecting high grade silicon steel as the material for stator and rotor. The iron losses depend on the frequency. The stator frequency is always supply frequency hence stator iron losses are dominate. As against this in rotor circuit, the frequency is very small which is slip times the supply frequency. Hence rotor iron losses are very small and hence generally neglected, in the running condition.

Mechanical losses:

The mechanical losses include frictional losses at the bearings and windings losses. The friction changes with speed but practically the drop in speed is very small hence these losses are assumed to be the part of constant losses.

Variable losses:

Variable losses include the copper losses in stator and rotor winding due to current flowing in the winding. As current changes as load changes as load changes, these losses are said to be variable losses. Generally stator iron losses are combined with stator copper losses at a particular load to specify total stator losses at particular load condition.

Rotor copper loss =$\boldsymbol{Pcu = 3\ I_{2r}^{2} R_{2}}$ ------------------------------------- analysed separately

Where, I_{2r} = Rotor current per phase at a particular load

R_2 = Rotor resistance per phase

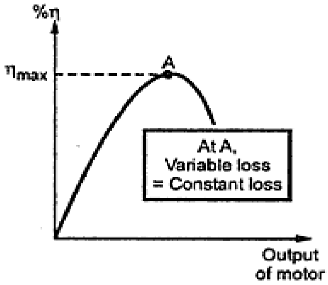
EFFICIENCY OF AN INDUCTION MOTOR:

"The ratio of output power available at the shaft (P_{out}) and the net electrical power input (P_{in}) to the motor is called as overall efficiency of an induction motor."

$$\boldsymbol{Efficiency = \frac{Output\ Power\ (Pout)}{Input\ Power\ (Pin)}}$$

$$\%\ \boldsymbol{Efficiency = \frac{Output\ Power\ (Pout)}{Input\ Power\ (Pin)} * 100}$$

MAXIMUM EFFICIENCY:



The maximum efficiency occurs when variable losses become equal to constant losses. When motor is on no load, current drawn by the motor is small. Hence efficiency is low. As load increases, current increases so copper losses also increases. When such variable losses achieve the same value as that of constant losses, efficiency attains its maximum value. If load is increased further, variable losses becomes greater than constant losses hence deviating from condition for maximum, efficiency starts decreasing.

7. What is meant by starter? Why starter is necessary for an induction motor to start and give its types

STARTER:

Starter is a device which is used to start the three phase induction motor

NECESSITY OF STARTER:

In a three phase induction motor, the magnitude of an induced e.m.f. in the rotor circuit depends on the slip of the induction motor. This induced e.m.f. effectively decides the magnitude of the rotor current. The rotor current in the running condition is given by,

$$I_{2r} = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

But at start, the speed of the motor is zero and slip is at its maximum i.e. unity. So magnitude of rotor induced e.m.f. is very large at start. As rotor conductors are short circuited, the large induced e.m.f. circulates very high current through rotor at start.

The condition is exactly similar to a transformer with short circuited secondary. Such a transformer when excited by a rated voltage circulates very high current through short circuited secondary. As secondary current is large, the primary also draws very high current from the supply.

Similarly in a three phase induction motor, when rotor current is high, consequently the stator draws a very high current from the supply. Similarly in a three phase induction motor, when rotor current is high, consequently the stator draws a very high current from the supply. This current can be of the order of 5 to 8 times the full load current, at start.

Due to such heavy inrush current at start there is possibility of damage of the motor winding. Similarly such sudden inrush of current causes large line voltage drop. Thus other appliances connected to the same line may be subjected to voltage spikes which may affect their working. To avoid such effects, it is necessary to limit the current drawn by the motor at start.

"***The starter is a device which is basically used to limit high starting current by supplying reduced voltage to the motor at the time of starting".***

Such a reduced voltage is applied only for short period and once rotor gets accelerated, full normal rated voltage is applied.

In three phases induction motors the starters operations are

- *To limits the starting current*
- *To protect against overloading loading*
- *To protect against low voltage situations*
- *To protect against single phasing*

The induction motor having rating below 5 h.p. can withstand starting currents hence such motors can be started directly on line. But such motors also need overload, single phasing and low voltage protection which is provided by a starter. Thus all the three phase induction motors need some or the other type of starter.

TYPES OF STARTERS:

The various types of starters for three phase induction motor is given by

- Stator resistance starter
- Autotransformer starter
- Star-delta starter
- Rotor resistance starter
- Direct on line starter

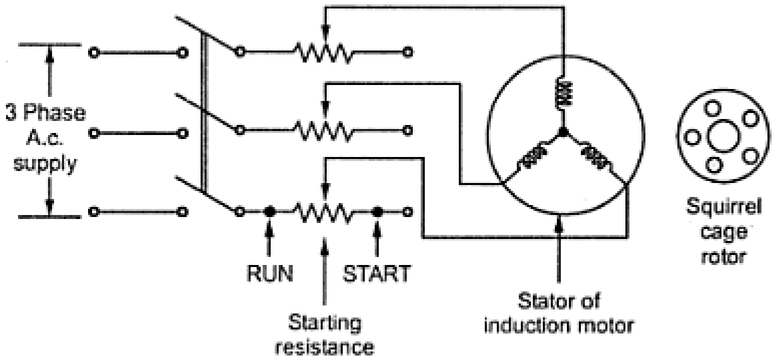
8. Explain the starting method of cage induction motors (APRIL/2014)

(or)

Explain any two starting methods of three phase induction motor. (NOV/2013)

1. STATOR RESISTANCE STARTER:

In order to apply the reduced voltage to the stator of the induction motor, three resistances are added in series with each phase of the stator winding. Initially the resistances are kept in maximum in the circuit. Due to its large voltage gets dropped across the resistances. Hence a reduced voltage gets applied to the stator which reduces the high starting current. The schematic diagram showing stator resistances is shown below figure.



Stator Resistance starter

When the motor starts running, the resistances are gradually cut-off from the stator circuit. When the resistances are entirely removed from the stator circuit i.e. rheostats in RUN position then rated voltage gets applied to the stator. Motor runs with normal speed.

Advantage:

- Simple in construction
- Cheap
- Can be used for both star and delta connected stator

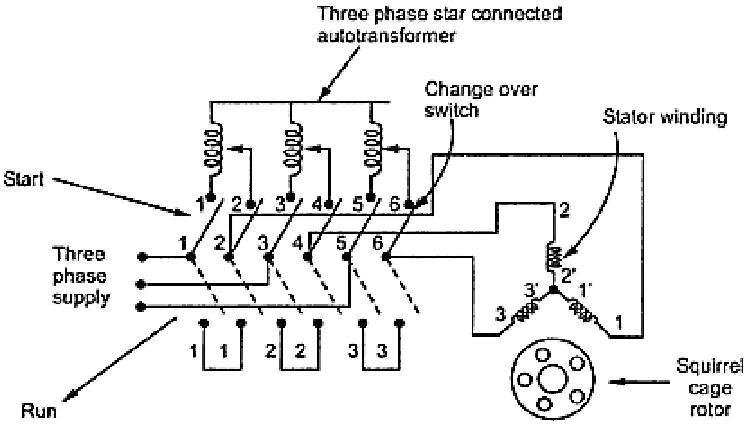
Disadvantage:

- Large power losses due to resistances.
- The starting torque of the motor reduces due to reduced voltage applied to the stator.

9. Explain the operation of star delta starter and auto transformer starter used for three phase induction motor. (NOV/2012)

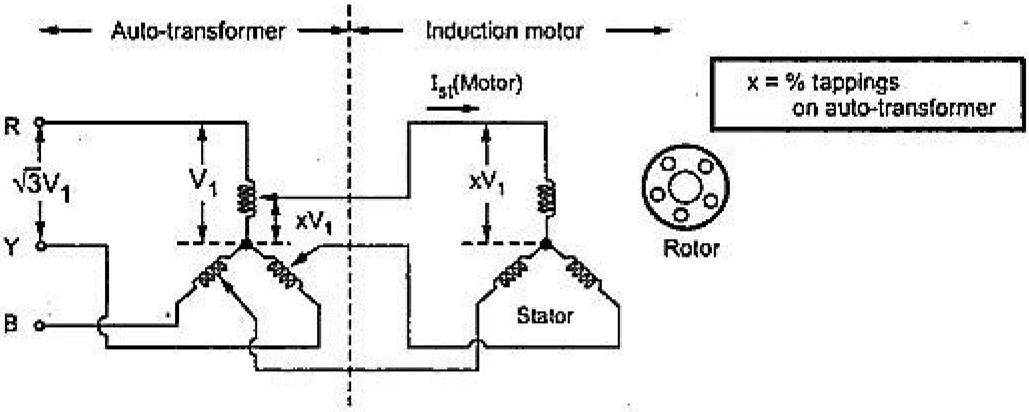
2. AUTOTRANSFORMER STARTER:

A three phase star connected autotransformer can be used to reduce the voltage applied to the stator. Such a starter is called an autotransformer starter. The schematic diagram of autotransformer starter is shown in the below figure.



Autotransformer starter

It consists of a suitable change over switch. When the switch is in the start position, the stator winding is supplied with reduced voltage. This can be controlled by tappings provided with autotransformer. The reduction in applied voltage by the fractional percentage tapping's x, used for an autotransformer is shown in the below figure.



Use of autotransformer to reduce voltage at start

When motor gathers 80% of the normal speed, the changeover switch is thrown into run position. Due to this, rated voltage gets applied to stator winding. The motor starts rotating with normal speed. Changing of switch is done automatically by using relays.

Advantages:

- The power loss is much less in this type of starting.
- Can be used for both star and delta connected motors.

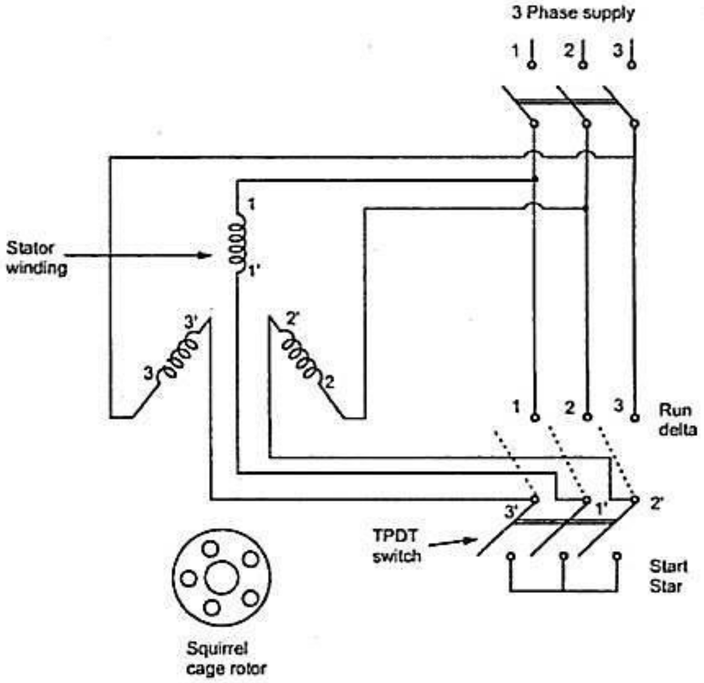
Disadvantage:

- It is expensive than stator resistance starter.

3. STAR - DELTA STARTER:

It is commonly used starter in three phase induction motor. It uses triple pole double throw (TPDT) switch. The switch connects the stator winding in star at start. Hence per phase voltage gets reduced by the factor 1/√3. Due to this reduced voltage, the starting current is limited.

When the switch is thrown on other side, the winding gets connected in delta, across the supply. So it gets normal rated voltage. The windings are connected in delta when motor gathers sufficient speed. The arrangement of star-delta starter is shown in the below figure.



Star-delta starter

The operation of the switch can be automatic by using relays which ensures that motor will not start with the switch in Run position.

Advantages:

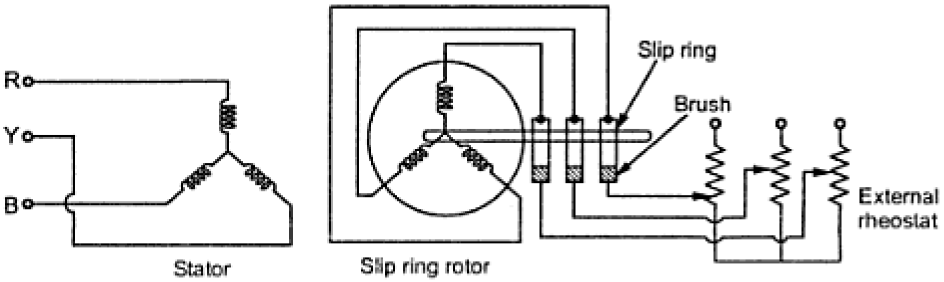
- The cheapest starter
- Maintenance free operation

Disadvantages:

- It is suitable for normal delta connected motors and the factor by which voltage changes is 1/√3 which cannot be changed.

4. ROTOR RESISTANCE STARTER:

To limit the rotor current which consequently reduces the current drawn by the motor from the supply, the resistance can be inserted in the rotor circuit at start. This addition of the resistance in rotor in the form of three phase star connected rheostat.



Rotor resistance starter

The external resistance is inserted in each phase of the rotor winding through slip ring and brush assembly. Initially maximum resistance is in the circuit. As motor gather speed, the resistance is gradually cut-off. The operation may be manual or automatic. We have seen that the starting torque is proportional to the rotor resistance.

Advantages:

- Improved starting torque for the motor

Disadvantages:

- Can be used only for slip ring induction motors

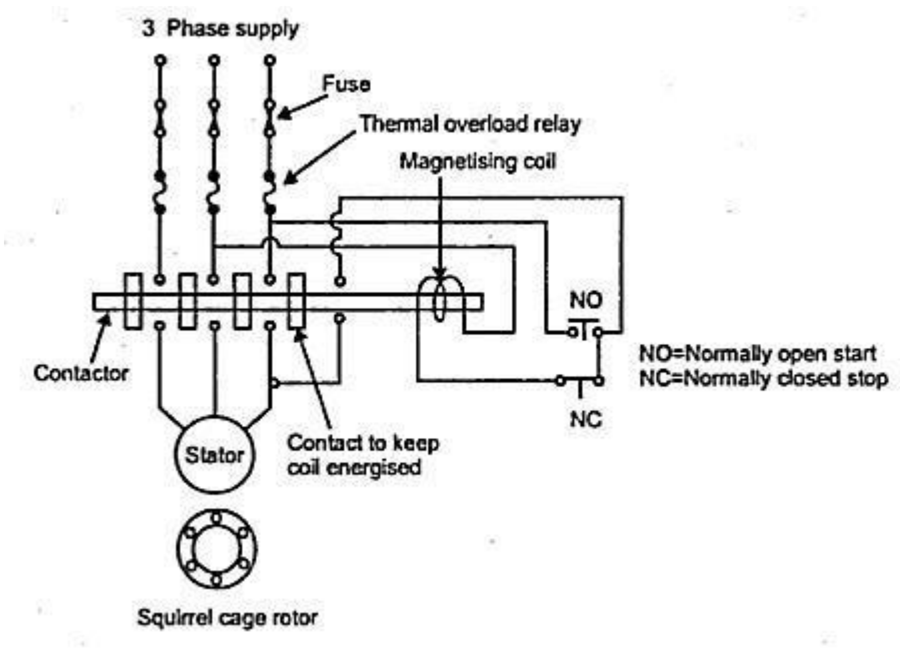
5. DIRECT ON LOAD LINE STARTER (D.O.L.):

In case of small capacity motors having rating less than 5 h.p., the starting current is not very high and such motors can withstand such starting current without any starter. Thus there is no need to reduce applied voltage, to control the starting current. Such motors use a type of starter which is used to connect stator directly to the supply lines without any reduction in voltage. Hence the starter is known as direct on line starter.

Though this starter does not reduce the applied voltage, it is used because it protects the motor from various severe abnormal conditions like over loading, low voltage, single phasing.

The **NO** contact is normally open and NC is normally closed. At start, NO is pushed for fraction of second due to which coil gets energized and attracts the contactor. So stator directly gets supply. The additional contact provided, ensures that as long as supply is ON, the coil gets supply and keeps contactor in ON position. When NC is pressed, the coil circuit gets opened due to which coil gets de-energized and motor gets switched OFF from the supply.

Under over load condition, current drawn by the motor increases due to which is an excessive heat produced, which increases temperature beyond limit. Thermal relays get opened due to high temperature, protecting the motor from overload conditions.



Direct Online starter

10. Discuss the various schemes used for speed control of 3 phase induction motor. (APRIL/2012)

SPEED CONTROL OF THREE PHASE INDUCTION MOTOR

A three phase induction motor is practically a constant speed motor like a D.C shunt motor. But the speed of D.C shunt motor can be varied smoothly just by using simple rheostats. This maintains the speed regulation and efficiency of D.C shunt motor. But in case of three phase induction motors it is very difficult to achieve smooth speed control. And if the speed control is achieved by some means, the performance of the induction motor in terms of its power factor, efficiency etc. gets adversely affected.

For the induction motor we know that,

$$N = N_S (1 - s)$$

From this expression it can be seen that the speed of induction motor can be changed either by changing its synchronous speed or by changing the slip s. Similarly torque produced in case of three phase induction motor is given by,

$$T\alpha \frac{sE_2^2R_2}{R_2^2 + (sX_2)^2}$$

So as the parameters like R_2, E_2 are changed then to keep the torque constant for constant load condition, motor reacts by change in its slip. Effectively its speed changes.

METHODS OF SPEED CONTROL:

The speed of the induction motor can be controlled by basically two methods:

- *From stator side*
- *From rotor side*

From stator side:

- Supply frequency control to control N_S, called V / f control.
- Supply voltage control.
- Controlling number of stator poles to control N_S.
- Adding rheostats in stator circuit.

*From rotor side***:**

- Adding external resistance in the rotor circuit.
- Cascade control.
- Injecting slip frequency voltage into the rotor circuit.

STATOR SIDE CONTROL:

1. Supply Frequency Control or V / f Control

The synchronous speed is given by,

$$N_S = 120f / P$$

Thus by controlling the supply frequency smoothly, the synchronous speed can be controlled over a wide range. This gives smooth speed control of an induction motor.

But the expression for the air gap flux is given by,

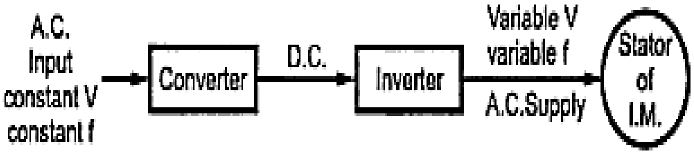
$$\Phi_g = \frac{1}{4.44 K_1 T_{ph1}} \left\{\frac{V}{f}\right\}$$

This is according to the e.m.f. equation of a transformer where,

K_1 = Stator winding constant
T_{ph1} = Stator turns per phase
V = Supply voltage
f = Supply frequency

From this expression that if the supply frequency f is changed, the value of air gap fluxes also gets affected. This may result into saturation of stator and rotor cores. Such saturation leads to the sharp increase in the (magnetization) no load current of the motor. Hence it is necessary to maintain air gap flux constant when supply frequency f is changed.

To achieve this, it can be seen from the above expression that along with f, V also must be changed so as to keep (V/f) ratio constant. This ensures constant air gap flux giving speed control without affecting the performance of the motor. Hence this method is called ***V / f control.***

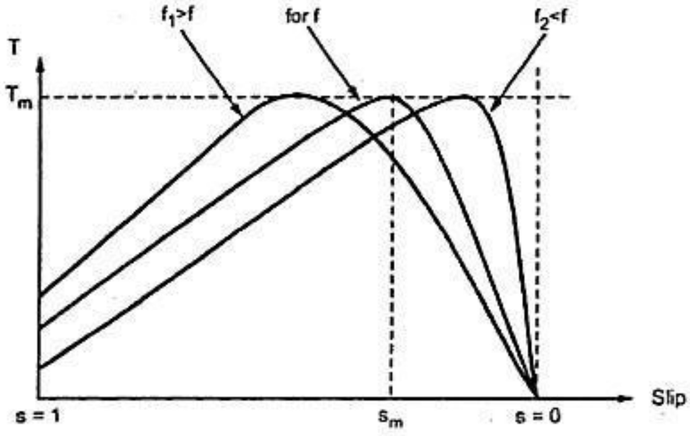


Electronic scheme for V/f control

Hence in this method, the supply to the induction motor required is variable voltage variable frequency supply and can be achieved by an electronic scheme using converter and inverter circuitry.

The normal supply available is constant voltage constant frequency A.C supply. The converter converts this supply into a D.C supply. This D.C supply is then given to the inverter. The inverter is a device which converts D.C supply, to variable voltage variable frequency A.C supply which is required to keep V / f ratio constant. By selecting the proper frequency and maintaining V / f constant, smooth speed control of the induction motor is possible.

If f is the normal working frequency then the below figure shows the torque-slip characteristics for the frequency $f_1 > f$ and $f_2 < f$ i.e. for frequencies above and below the normal frequency.



Torque-slip characteristics with variable f and constant (V/f)

Disadvantages:

- The supply obtained cannot be used to supply other devices which require constant voltage. Hence an individual scheme for a separate motor is required
- This method is costly

2. Supply (or) Stator Voltage Control

We know that,

$$T\alpha\ \frac{s\,E_2^2R_2}{R_2+\ (s\,X_2)}$$

Now E_2, the rotor induced e.m.f. at standstill depends on the supply voltage V.

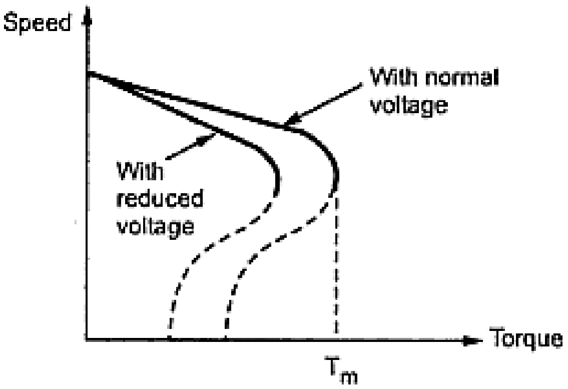
$$\mathbf{E_2\quad \alpha\ V}$$

Also for low slip region, which is operating region of the induction motor, $(s\ X_2)^2 << R_2$ and hence can be neglected.

$T\ \alpha\ S\ V^2\ R_2/R_2^2 + S\ V^2$ for constant R_2^2

Now if supply voltage is reduced below rated value, as per above equation torque produced also decreases. But to supply the same load it is necessary to develop same torque hence value of slip increases so that torque produced remains same. Slip increases means motor reacts by running at lower speed, to decrease in supply voltage. So motor produces the required load torque at a lower speed. The speed-torque characteristics for the motor using supply voltage control are shown in the below figure.

But in this method, due to reduction in voltage, current drawn by the motor increases. Large change in voltage for small change in speed is required is the biggest disadvantage.



Speed-torque curves for motor with voltage control

Disadvantage:

Due to increased current, the motor may get overheated. Additional voltage changing equipment is necessary. Hence this method is rarely used in practice.

Due to reduced voltage, E2 decreases, decreasing the value of maximum torque too.

Application:

Motors driving fan type of loads use this method of speed control.

3. Controlling Number of Poles

In this method poles are changed to control the speed of three phase induction motors. In this method, it is possible to have one, two or four speeds in steps, by the changing the number of stator poles. A continuous smooth speed control is not possible by this method.

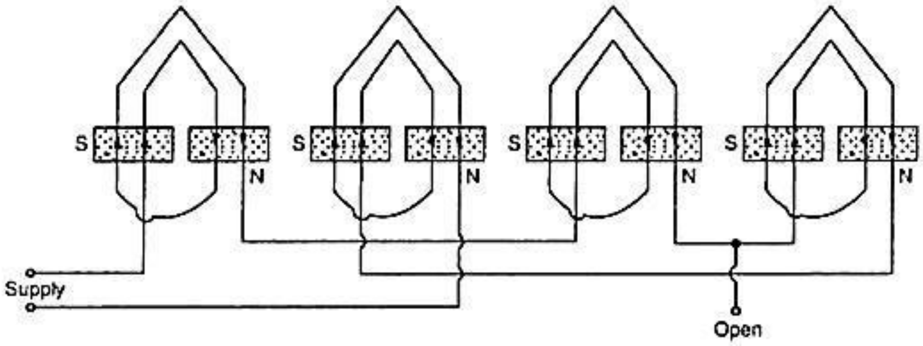
The stator poles can be changed by following methods:

(i). Consequent poles method
(ii).Multiple stator winding method
(iii). Pole amplitude modulation method.

(i). Consequent Poles Method

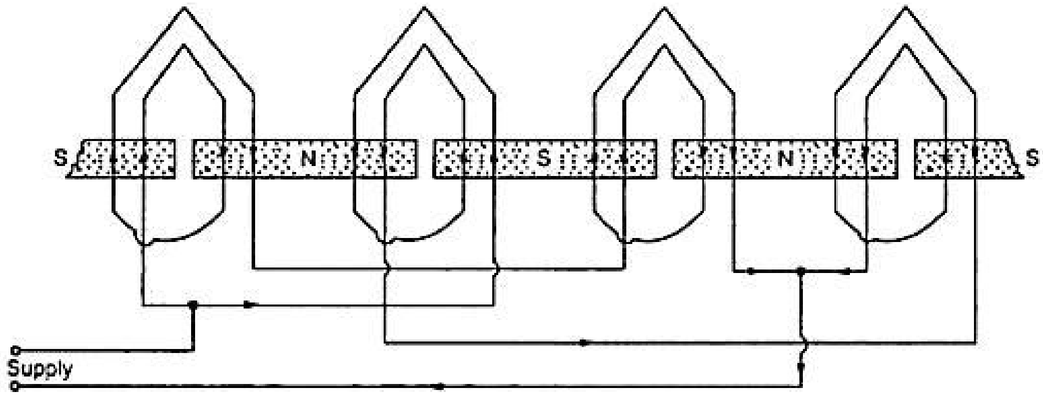
In this method, connections of the stator winding are changes with the help of simple switching. Due to this, the number of stator poles gets changed in the ratio 2:1. Hence either of the two synchronous speeds can be selected. Consider the pole formation due to single phase of a three phase winding, as shown in the below figure. There are three tapping points to the stator winding. The supply is given to two of them and third is kept open.

It can be seen that current in all the parts of stator coil is flowing in one direction only. Due to this, 8 poles get formed as shown in the below figure. So synchronous speed possible with this arrangement with 50 Hz frequency is N_s = 750 r.p.m.



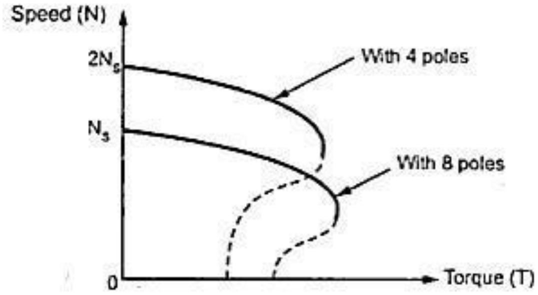
Pole winding

If the two terminals to which supply was given either are joined together and supply is given between this common point and the open third terminal, the poles are formed as in below figure.



Pole Winding

It can be seen that the direction of current through remaining two. Thus upward direction is forming say S pole and downward say N. it can be observed that in this case only 4 poles are formed. So the synchronous speed possible is 1500 r.p.m. for 50 Hz frequency.

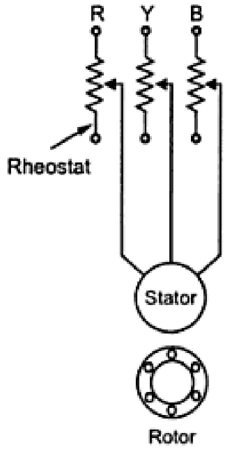


Thus series/parallel arrangements of coils can produce the poles in the ratio 2 : 1. But the speed change is in step and smooth speed control is not possible. Similarly the method can be used only for the squirrel cage type motors as squirrel rotor adjusts itself to same number of poles as stator which is not the case in slip ring induction motor.

(ii). Multiple Stator Winding Method

In this method instead of one winding, two separate stator winding are placed in the stator core. The windings are placed in the stator slots only but are electrically isolated from each other. Each winding is divided into coils to which, pole changing with consequent poles, facility is provided. Thus giving supply to one of the two windings and using switching arrangement, two speeds can be achieved. Same is true for other stator winding. So in all four different speeds can be obtained.

4. Adding Rheostats in Stator Circuit



The reduced voltage can be applied to the stator by adding the rheostats in the stator circuit. The part of the voltage gets dropped across the resistances and reduced voltage gets applied across the stator. The reduction in stator voltage causes reduction in the speed. The rheostats can be varied as per the required change in speed. But the entire line current flows through the rheostats and hence there are large power losses. The method is not efficient from speed control point of view hence used as a starter rather than as a speed control method.

ROTOR SIDE CONTROL:

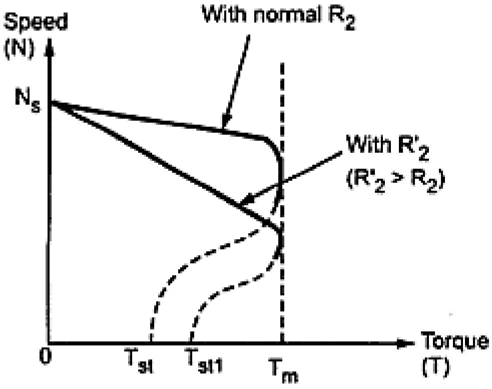
1. Adding External Resistance in Rotor Circuit

$$T\alpha \, \frac{s\,E_2^2 R_2}{R_2 + \,(s\,X_2)}$$

For low slip region (s $(sX_2)^2 \ll R_2$ and can be neglected and for constant supply voltage is also constant

$$T \infty \frac{sR_2}{R_2} \infty \frac{s}{R_2}$$

Thus if the rotor resistance is increased, the torque produced decreases. But when the load on the motor is same, motor has to supply same torque as load demands. So motor reacts by increasing its slip to compensate decreases in T due to R_2 and maintains the load torque constant. So due to that additional rotor resistance R_2, motor slip increases i.e. the speed of the motor decreases. Thus by increasing the rotor resistance R_2, speeds below normal value can be achieved. Another advantage of this method is that the starting torque of the motor increases proportional to rotor resistance. This method is rarely used in the practice due to the following disadvantages.



Torque-speed curves for rotor resistance control

Disadvantages:

- The large speed changes are not possible. This is because for large speed change, large resistance is required to be introduced in rotor which causes large rotor copper loss due to reduce the efficiency.
- The method cannot be used for the squirrel cage induction motors.
- The speeds above the normal values cannot be obtained.
- Large power losses occur due to large loss.
- Sufficient cooling arrangements are required which make the external rheostats bulky be expensive.
- Due to large power losses, efficiency is low.

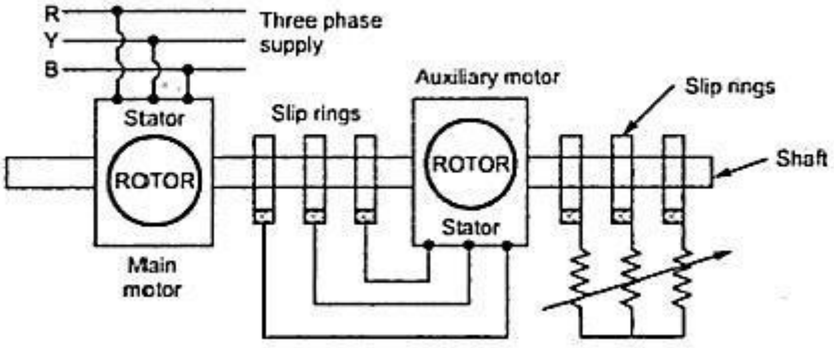
11. Explain about the concatenation connection of three phase induction motor with neat diagram

2. *Cascade Control:*

Cascade control is also called ***Concatenation*** or ***Tandom operation*** of the induction motors. Here, two induction motors are mounted on the same shaft. One of the two motors must be of slip ring type which is called main motor. The second motor is called auxiliary motor. The arrangement of this cascade method is shown below.

The auxiliary motor can be slip ring or squirrel cage type. The stator of the main motor is connected to the three phase supply. While the supply of the auxiliary motor is derived at a slip frequency from the slip rings of the main motor. This is called **cascading** of the motors. If the torque produced by both act in the same direction, cascading is called **cumulative cascading**. If torques produced is in opposite direction, cascading is called **differential cascading**.

Let, P_A = Number of poles of main motor
P_B = Number of poles of auxiliary motor
f = Supply frequency



Cascade control of two induction motor

$$N_{sA} = \frac{120\,f}{P_A}$$

N = Speed of the set

The speed N is same for both the motors as motors are mounted on the same shaft.

$$s_A = \frac{N_{sA} - N}{N_{sA}}$$

Now f_A = Frequency of rotor induced e.m.f. of motor A

$\therefore$ $f_A = s_A f$ ... as $f_r = s\,f$

Now on no load, the speed of the rotor B i.e. N is almost equal to its synchronous speed N_{sB}.

$$\therefore \quad N_{sB} = N$$

$$\therefore \quad N = 120\left(\frac{N_{sA} - N}{N_{sA}}\right) \times \frac{f}{P_B}$$

$$\therefore \quad N = \frac{120\,f}{P_B} \times \left[1 - \frac{N}{N_{sA}}\right]$$

$$\therefore \quad N = \frac{120\,f}{P_B} \times \left[1 - \frac{N}{\left(\frac{120 f}{P_A}\right)}\right]$$

$$\therefore \quad N = \frac{120\,f}{P_B}\left[1 - \frac{NP_A}{120\,f}\right]$$

$$\therefore \quad N\left[1 + \frac{P_A}{P_B}\right] = \frac{120\,f}{P_B}$$

$$\therefore \quad \boxed{N = \frac{120\,f}{P_A + P_B}}$$

If by interchanging any two terminals of motor B, the reversal of direction of rotating magnetic field of B is achieved then the set runs as differentially cascaded set. And in such a case effective number of poles is P_A- P_B.

Thus in cascade control, four different speeds are possible as,

- With respect to synchronous speed of A independently,

$$N_{sA} = \frac{120f}{P_A}$$

- With respect to synchronous speed of B independently with main motor is disconnected and B is directly connected to supply,

$$N_{sB} = \frac{120f}{P_B}$$

- Running set as cumulatively cascaded with,

$$N = \frac{120f}{P_A + P_B}$$

- Running set as differentially cascaded with,

$$N = \frac{120f}{P_A - P_B}$$

Disadvantages:

- It requires two motors which makes the set expensive.
- Smooth speed control is not possible.
- Operation is complicated.
- The starting torque is not sufficient to start the set.
- Set cannot be operated if $P_A = P_B$.

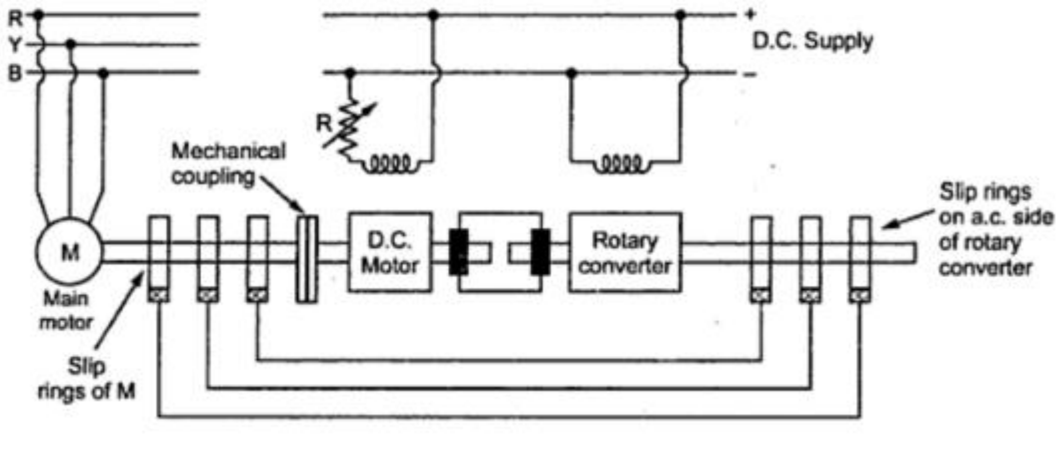
3. **Injecting Slip-Frequency E.M.F. into Rotor Circuit:**

In this method, a voltage is injected in the rotor circuit. The frequency of rotor circuit is a slip frequency and hence the voltage to be injected must be at a slip frequency. It is possible that the injected voltage may oppose the rotor induced e.m.f. or may assist the rotor induced e.m.f. If it is in the phase opposition, effective rotor resistance increases. If it is in the phase of rotor induced e.m.f., effective rotor resistance decreases. Thus by controlling the magnitude of the injected e.m.f., rotor resistance and effectively speed can be controlled.

Practically two methods are available which use this principle. These methods are,

- ***Kramer system***
- ***Scherbius system***

KRAMER SYSTEM:



Kramer system

This system consists of main induction motor M, speed of which is to be controlled. A DC motor & rotary converter is used. The slip rings of main motor are connected to AC side of rotary converter.

The D.C side of rotary converter feeds a D.C shunt motor commutator, which is directly connected to the shaft of the main motor. Rotary converter converts the low-slip frequency A.C power into D.C power supplied from main line so that its speed derivates from a fixed value only to the extent of the slip of auxiliary induction motor. Both dc motor & rotary converter are excited from a separate DC supply. The variable resistance introduces the field circuit of a DC motor, which act as a field regulator. The speed of the set is controlled by varying the field of DC motor with rheostat R when the field rheostat is changed, the back E.M.F of motor change. Thus D.C voltage at the commutator changes, this changes D.C voltage on the D.C side of rotary converter. Now Rotary converter has a fixed ratio between its A.C & D.C side voltages. Thus Voltage on its A.C side also changes. This A.C voltage is given to the slip ring of that main motor. So the voltage injected in the rotor of main motor which produces the required speed control.

Application:

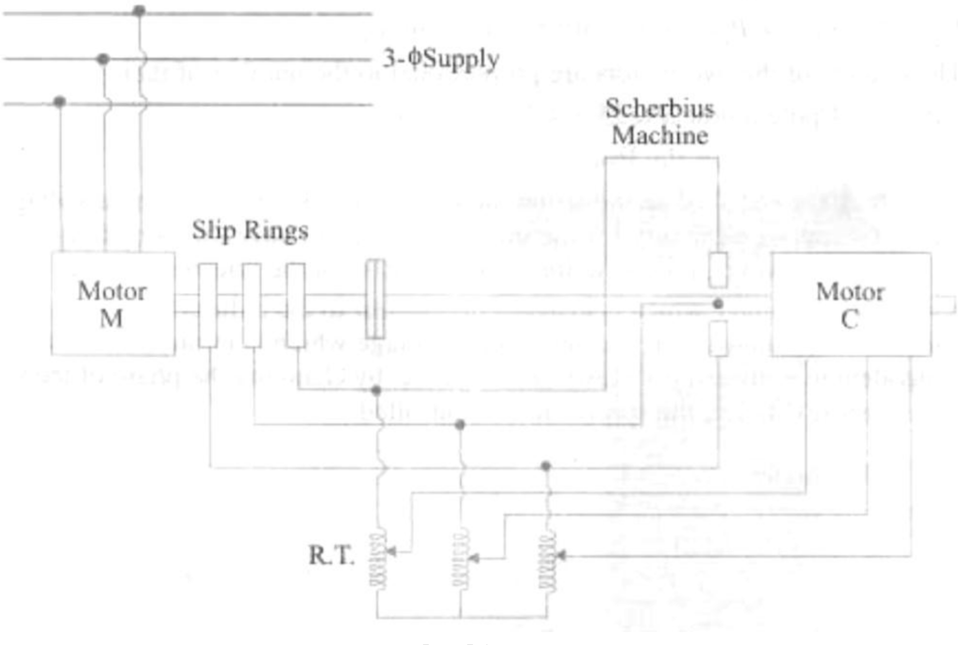
- Very large motors (above 4000kw) such a steel rolling mills use this type.

Advantages:

- Smooth speed control is possible.
- Wide range of speed control is possible.
- Design of rotary converter is independent of speed control required.
- If rotary converter is excited, it draws leading current & hence power factor can be improved.

SCHERBIUS SYSTEM:

This is another method for controlling a large size induction motors. The slip energy is not converted into DC and then fed to a DC motor; rather it is fed directly to a special three phase (or) six phase AC commutator motor called a Scherbius machine. The poly phase winding of machine C is supplied with the low-frequency output of machine M through a regulating transformer RT. The commutator motor C is a variable-speed motor and its speed is controlled by either varying the tappings on RT or by adjusting the position of brushes on C.



Scherbius system

12. Explain about the construction and working operation of an single phase induction motor

SINGLE PHASE INDUCTION MOTOR

Single phase motors are the most familiar of all electric motors because they are extensively used in home appliances, shops, offices due to availability for single phase supply worldwide very easy. These AC motors are called single phase induction motors. The power rating of such motors is very small. Some of them are even fractional horse power motors, which are used in applications like small toys, small fans, hair dryers etc.

CONSTRUCTION OF SINGLE PHASE INDUCTION MOTORS

Single phase induction motor has basically two main parts.

- **Stator** *(stationary parts in motor)*
- **Rotor** *(rotating parts in motor)*

STATOR:

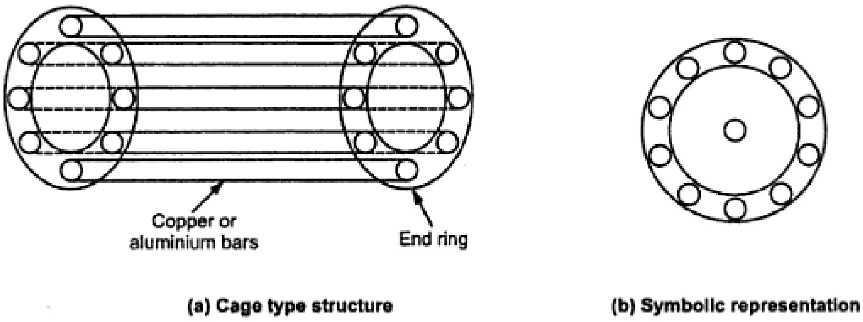
The stator has laminated construction, made up of stampings. The stampings are slotted on its inner periphery to carry the winding called stator winding or main winding. This is excited by a single phase A.C supply. The laminated construction keeps iron losses (or) core loss to minimum. The stampings are made up of high graded silicon steel which minimizes the *hysteresis loss*. The stator winding is wound for certain definite number of poles means when excited by single phase AC supply, stator produces the magnetic field which creates the effect of certain definite number of poles. The number of poles for which stator winding is wound, decides the synchronous speed of the motor. The synchronous speed is denoted as N_S and it has a fixed relation with supply frequency f and number of poles P. The relation is given by,

$$N_S = \frac{120\,f}{P}$$

The induction motor never rotates with the synchronous speed but rotates at a speed which is slightly less than the synchronous speed.

ROTOR:

The rotor construction is of squirrel cage type as that of in three phase motor. Rotor consists of uninsulated copper or aluminium bars, placed in the slots. The bars are permanently shorted at both the ends with the help of conducting rings called ***end rings***. The entire structure looks like cage hence called squirrel cage rotor. The construction and symbol is shown in the below figure.

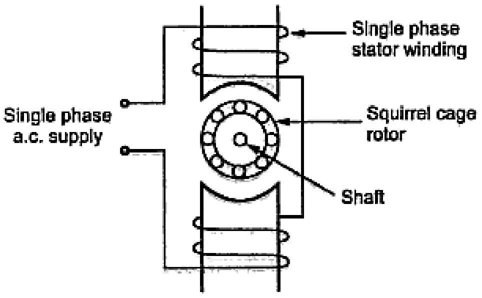


(a) Cage type structure (b) Symbolic representation

As the bars are permanently shorted to each other, the resistance of the entire rotor is very very small. The air gap between stator and rotor is kept uniform and as small as possible. The main feature of this rotor is that it automatically adjusts itself for same number of poles as that of the stator winding.

WORKING PRINCIPLE OF SINGLE PHASE INDUCTION MOTOR

The schematic representation of single phase induction motor is shown in the below figure. For the motoring action, there must exist two fluxes which interact with each other to produce the torque. In the single phase induction motor, single phase AC supply is given to the stator winding. The stator winding carries an alternating current which produces the flux which is also alternating in nature. This flux is called ***main flux.***



This flux links with the rotor conductors and due to transformer action e.m.f. gets induced in the rotor. The induced e.m.f. drives current through the rotor as rotor circuit is closed circuit. This rotor current produces another flux called ***rotor flux*** required for the motoring action. Thus second flux is produced according to induction principle due to induced e.m.f. hence the motor is called ***induction motor***.

As against this in DC motor a separate supply is required to armature to produce armature flux. This is an important difference between DC motor and an induction motor. Another important difference between the two is that the DC motors are self-starting while ***single phase induction motors are not self-starting***.

13. Explain the operation of single phase induction motor on the basic of double field revolving theory with neat sketch. (11) (NOV/2014)

DOUBLE REVOLVING FIELD THEORY

According to double revolving field theory, any alternating quantity can be resolved into two rotating components which rotate in opposite directions and each having magnitude as half of the maximum magnitude of the alternating quantity. In case of single phase induction motors, the stator winding produces an alternating magnetic field having maximum magnitude of Φ_{1m}.

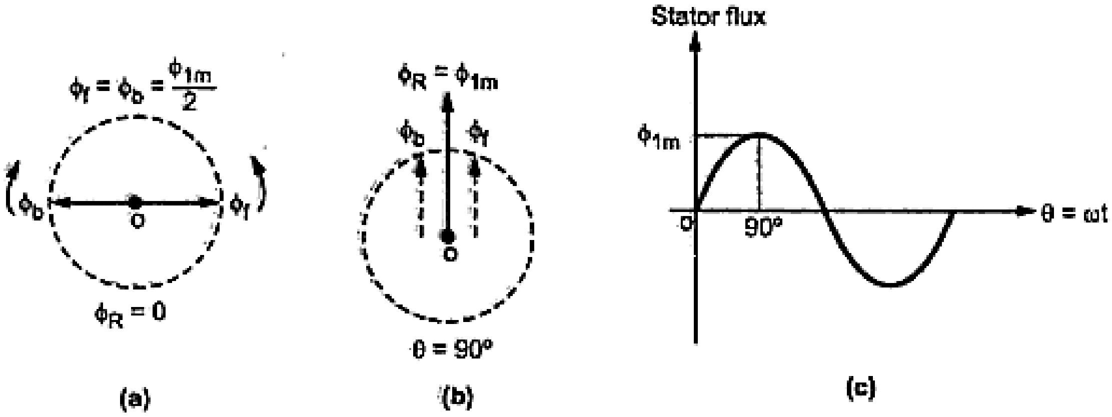
According to double revolving field theory, consider the two components of the stator flux, each having magnitude half of maximum magnitude of stator flux i.e. ($\Phi_{1m}/2$). Both these components are rotating in opposite directions at the synchronous speed N_S which is dependent on frequency and stator poles.

Let

Φ_f is forward component rotating in anticlockwise direction

Φ_b is the backward component rotating in clockwise direction.

The resultant of these two components at any instant gives the instantaneous value of the stator flux at the instant. So resultant of these two is the original stator flux.



Stator flux and its two components

The above figure shows the stator flux and its two components **Φ_f** and **Φ_b**. At start both the components are shown opposite to each other in the above figure (a). Thus the resultant $\Phi_R = 0$. This is nothing but the instantaneous value of the stator flux at start. After 90^0 as shown in the above figure (b), the two components are rotated in such a way that both are pointing in the same direction. Hence the resultant Φ_R is the algebraic sum of the magnitudes of the two components.

So $\mathbf{\Phi_R = (\Phi_{1m}/2) + (\Phi_{1m}/2) = \Phi_{1m}}$.

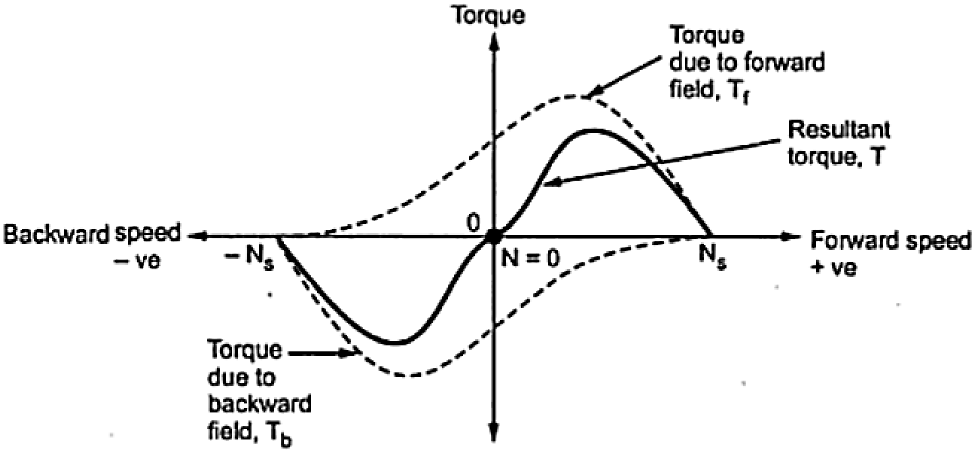
This is nothing but the instantaneous value of the stator flux at $\theta = 90^{o}$ as shown in the above figure (c). Thus continuous rotation of the two components gives the original alternating stator flux.

Both the components are rotating and hence get cut by the motor conductors. Due to cutting of flux, e.m.f. gets induced in rotor which circulates rotor current. The rotor current produces rotor flux. This flux interacts with forward component Φ_f to produce a torque in one particular direction say anticlockwise direction. While rotor flux interacts with backward component Φ_b to produce a torque in the clockwise direction. So if anticlockwise torque is positive then clockwise torque is negative.

At start, these two torques are equal in magnitude but opposite in direction. Each torque tries to rotate the rotor in its own direction. Thus ***net torque experienced by the rotor is zero at start***. And hence the single phase induction motors are not self-starting.

TORQUE SPEED CHARACTERISTICS

The two oppositely directed torques and the resultant torque can be shown effectively with the help of torque-speed characteristics. It is shown in the below figure.



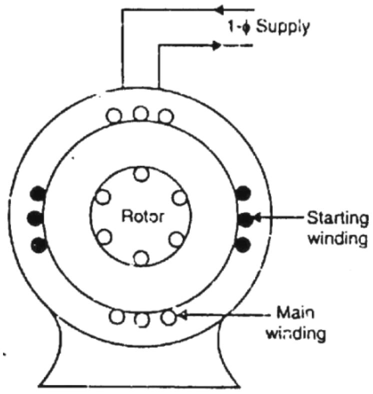
Torque-speed characteristics

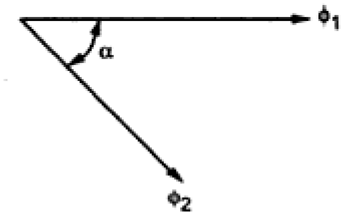
It can be seen that at start N = 0 and at that point resultant torque is zero. So single phase motors are not self-starting. However if the rotor is given an initial rotation in any direction, the resultant average torque increase in the direction in which rotor initially rotated. And motor starts rotating in that direction. But in practice it is not possible to give initial torque to rotor externally hence some modifications are done in the construction of single phase induction motors to make them self-starting.

MAKING SELF-STARTING SINGLE PHASE MOTOR:

The single-phase induction motor is not self- starting and it is undesirable to give mechanical spinning of the shaft to start it. To make a single-phase induction motor self-starting, a revolving stator magnetic field is required. This may be achieved by converting a single-phase supply into two-phase supply through the use of an additional winding. When the motor attains sufficient speed, the starting means (i.e., additional winding) may be removed depending upon the type of the motor. As a matter of fact, single-phase induction motors are classified and named according to the method employed to make them self-starting.

The construction of two phase motor and two fluxes having phase difference of between them are shown in the below.

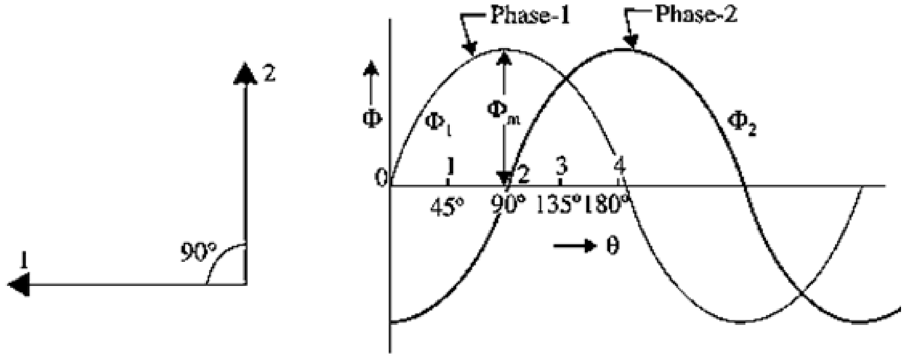




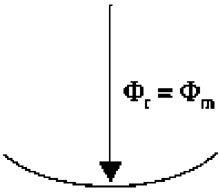
More the phase difference angle **α**, more is starting torque produced.

PRODUCTION OF ROTATING FIELD FROM TWO-PHASE SUPPLY:

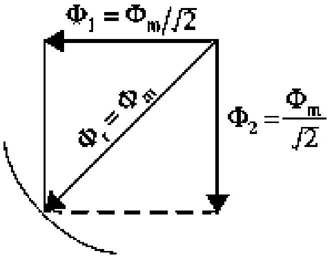
It will now be shown that when stationary coils, wound for two phases are supplied by two phase supply respectively, a uniformly-rotating (or revolving) magnetic flux of constant value is produced.



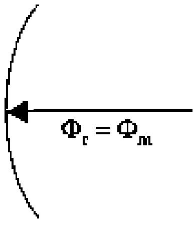
The principle of a two phase, 2-pole stator having two identical windings, 90^0 spaces apart, is illustrated in the above figure. The flux due to the current flowing in each phase winding is assumed sinusoidal and is represented in the above figure. The assumed positive directions of fluxes are shown in above figure.



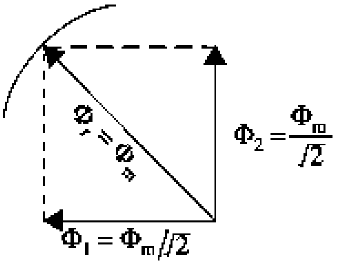
(i) θ = 0°



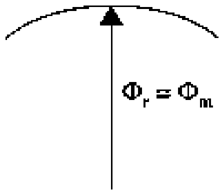
(ii) θ = 45°



(iii) θ = 90°



(iv) θ = 135°



(i) θ = 180°

Let Φ_1 and Φ_2 be the instantaneous values of the fluxes set up by the two windings. The resultant flux Φ_r at any time is the vector sum of these two fluxes (Φ_1 and Φ_2) at that time. We will consider conditions at intervals of 1/8th of a time period i.e. at intervals corresponding to angles of 0^0, 45^0, 90^0, 135^0 and 180^0. It will be shown that resultant flux Φ_r is constant in magnitude i.e.

equal to Φ_m – the maximum flux due to either phase and is making one revolution/cycle. In other words, it means that the resultant flux rotates synchronously.

- When $\theta = 0^0$ i.e., corresponding to point 0 in the above figure, $\Phi_1 = 0$, but Φ_2 is maximum i.e. equal to Φ_m and negative. Hence, resultant fluxes $\Phi_R = \Phi_m$ and, being negative, is shown by a vector pointing downwards [Figure (i)].
- When $\theta = 45^0$ i.e. corresponding to point 1 in above figure. At this instant, $\Phi_1 = \Phi_m/\sqrt{2}$ and is positive; $\Phi_2 = \Phi_m/\sqrt{2}$ but is still negative. Their resultant, as shown in figure (ii), is $\varphi_r = \sqrt{[\left(\frac{\varphi m}{\sqrt{2}}\right)^2 + \left(\frac{\varphi m}{\sqrt{2}}\right)^2]} = \Phi_m$ although this resultant has shifted 45^0 clockwise.
- When $\theta = 90^0$ i.e. corresponding to point 2 in above figure. Here $\Phi_2 = 0$, but $\Phi_1 = \Phi_m$ and is positive. Hence, $\Phi_r = \Phi_m$ and has further shifted by an angle of 45^0 from its position by 90^0 from its original position as shown in figure (iii).
- When $\theta = 135^0$ i.e. corresponding to point 3 in above figure. Here, $\Phi_1 = \Phi_m/\sqrt{2}$ and is positive, $\Phi_2 = \Phi_m/\sqrt{2}$ and is also positive. The resultant $\Phi_r = \Phi_m$ and has further shifted clockwise by another 45^0, as shown in figure (iv).
- When $\theta = 180^0$ i.e. corresponding to point 4 in above figure Here, $\Phi_1 = 0$, $\Phi_2 = \Phi_m$ and is positive. Hence, $\Phi_r = \Phi_m$ and has shifted clockwise by another 45^0 or has rotated through an angle of 180^0 from its position at the beginning as shown in figure (v).

Hence, we conclude

- That the magnitude of the resultant flux is constant and is equal to Φ_m, the maximum flux due to either phase.
- That the resultant flux rotates at synchronous speed given by $N_S = 120f / P$ rpm.

14. What are the types of single phase induction motor? Explain about any two types of single phase induction motor

TYPES OF SINGLE PHASE INDUCTION MOTOR

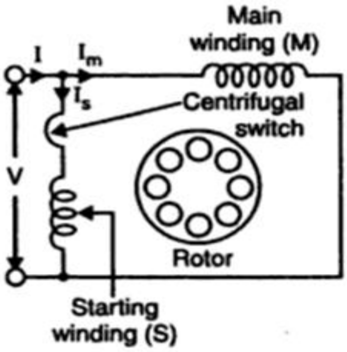
- *Split-phase motors*
- *Capacitor start motors*
- *Capacitor start Capacitor run motors*
- *Shaded-pole motors*

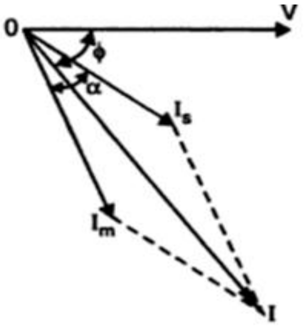
1. SPLIT-PHASE INDUCTION MOTOR

Construction:

The stator of a split-phase induction motor is provided with an ***auxiliary or starting winding S*** in addition to the ***main or running winding M***. The starting winding is located 90° electrical from the main winding and operates only during the short period when the motor starts up. A centrifugal switch is connected in series with starting winding.

The two windings are so designed that the ***starting winding S*** has a ***high resistance*** and ***Low reactance*** while the ***main winding M*** has relatively ***low resistance*** and ***large reactance*** as shown in the schematic connections. Consequently, the currents flowing in the two windings have reasonable phase difference (25° to 30°) as shown in the phasor diagram.





Operation

When the two stator windings are energized from a single-phase supply, the main winding carries current $\mathbf{I_m}$ while the starting winding carries current $\mathbf{I_S}$. Since main winding is made highly inductive while the starting winding highly resistive, the currents I_m and I_S have a reasonable phase angle a (25° to 30°) between them as shown in Phasor diagram. Consequently, a weak revolving field approximating to that of a 2-phase machine is produced which starts the motor.

The starting torque is given by;

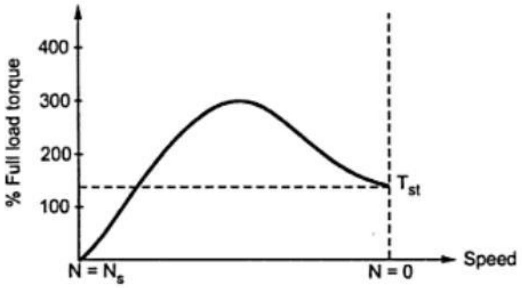
$$\mathbf{T_S = k\, I_m\, I_S \sin \alpha}$$

Where, ***k*** *is a constant whose magnitude depends upon the design of the motor.*

When the motor reaches about 75% of synchronous speed, the centrifugal switch opens the circuit of the starting winding. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed. The normal speed of the motor is below the synchronous speed and depends upon the load on the motor.

Characteristics

- The spinning torque is 1.5 to 2 times the full-load torque mid (ie., starting current is 6 to 8 times the full-load current.)
- Due to their low cost, split-phase induction motors are most popular single-phase motors in the market.



- Since the starting winding is made of fine wire, the current density is high and the winding heats up quickly. If the starting period exceeds 5 seconds, the winding may burn out unless the motor is protected by built-in-thermal relay. This motor is, therefore, suitable where starting periods is short.
- An important characteristic of these motors is that they are essentially constant-speed motors. The speed variation is 2-5% from no-load to full-load.
- The power rating of such motors generally lies between 60 W and 250 W

Applications:

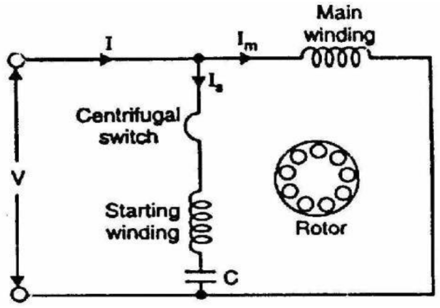
- Fans
- Washing machines
- Oil burners
- Centrifugal pumps
- Small machine tools etc.

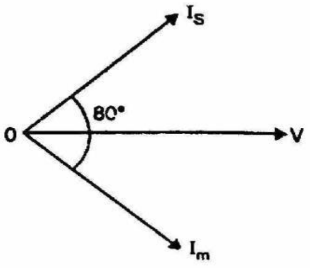
15. Explain why the single phase induction motors are not self-starting? Describe the operation of capacitor start and run motors in detail. (APRIL/2014)

2. CAPACITOR-START MOTOR

Construction:

The capacitor-start motor is identical to a split-phase motor except that the starting winding has as many turns as the main winding. Moreover, a ***capacitor C*** is connected in series with the starting winding as shown in below figure. The value of capacitor is so chosen that I_S leads I_m by about 80° (i.e., $\alpha \simeq 80°$) which is considerably greater than 25° found in split-phase motor.





Operation:

A single phase supply is given to the two winding of stator. The starting current I_S leads the line voltage due to the presence of a capacitor in series with starting winding. The running current I_m lags the line voltage. The phase displacement between these two currents is approximately equal to 90^0 during starting period. Consequently, starting torque ($T_S = k\ I_m\ I_S\ \sin\alpha$) is much more than that of a split-phase motor. Again, the starting winding is opened by the centrifugal switch when the motor attains about 75% of synchronous speed. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed.

Characteristics:

- Although starting characteristics of a capacitor-start motor are better than those of a split-phase motor, both machines possess the same running characteristics because the main windings are identical.
- The phase angle between the two currents is about 80° compared to about 25° in a split-phase motor. Consequently, for the same starting torque, the current in the starting winding is only about half that in a split-phase motor. Therefore, the starting winding of a capacitor start motor heats up less quickly and is well suited to applications involving either frequent or prolonged starting periods.
- Capacitor-start motors are used where high starting torque is required and where the starting period may be long enough to drive.
- The power rating of such motors lies between 120 W and 7500 W

Applications:

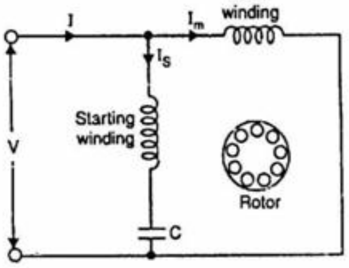
- Compressors
- Large fans
- Pumps
- Refrigerators
- High inertia loads

3. CAPACITOR-START CAPACITOR-RUN MOTOR

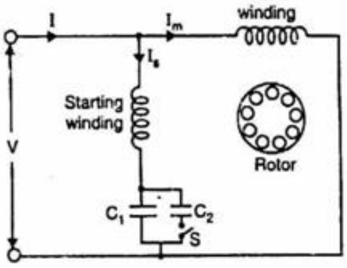
Construction and Operation:

This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting. Two designs are generally used.

- In one design, a single capacitor C is used for both starting and running as shown in figure(i). This design eliminates the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.
- In the other design, two capacitors C_1 and C_2 are used in the starting winding as shown in figure (ii). The smaller capacitor C_1 required for optimum running conditions is permanently connected in series with the starting winding. The much larger capacitor C_2 is connected in parallel with C_1 for optimum starting and remains in the circuit during starting. The starting capacitor C_1 is disconnected when the motor approaches about 75% of synchronous speed. The motor then runs as a single-phase induction motor.



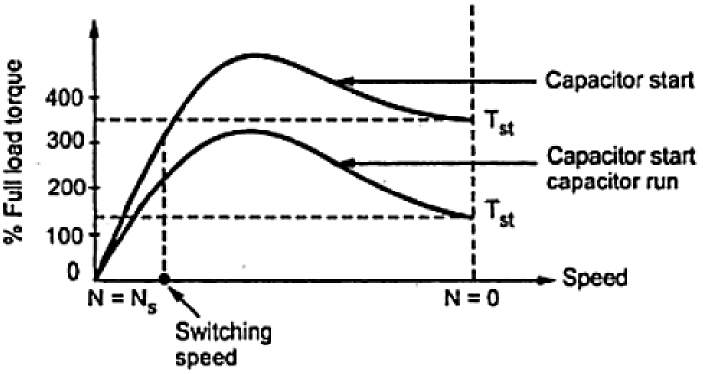
(i)



(ii)

Characteristics:

- The starting winding and the capacitor can be designed for perfect 2-phase operation at any load. The motor then produces a constant torque and not a pulsating torque as in other single-phase motors.
- Because of constant torque, the motor is vibration free and can be used in places where silence is important.



Applications:

- Hospitals
- Studios

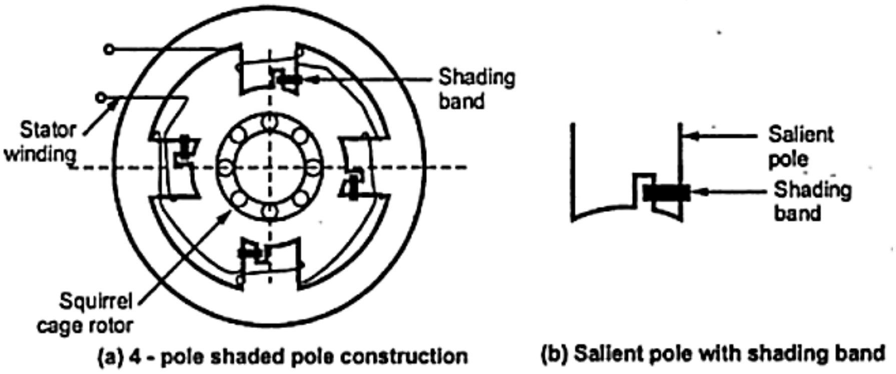
4. SHADED POLE INDUCTION MOTOR

Construction:

This type of motor consists of a ***squirrel cage rotor*** and ***stator*** consisting of ***salient poles*** i.e. projected poles. The poles are shaded i.e. each pole carries a copper band on one of its unequally divided part called ***shading band.*** Figure (a) shows 4 pole shaded pole construction while figure (b) shows a single pole consisting of copper shading band.

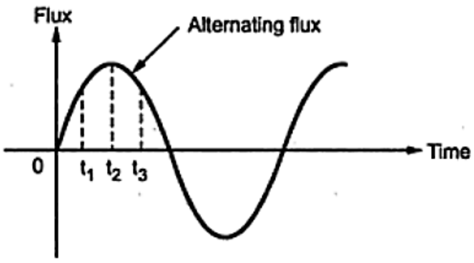
Operation:

When single phase AC supply is given to the stator winding, due to shading provided to the poles, a rotating magnetic field is generated.



(a) 4 - pole shaded pole construction (b) Salient pole with shading band

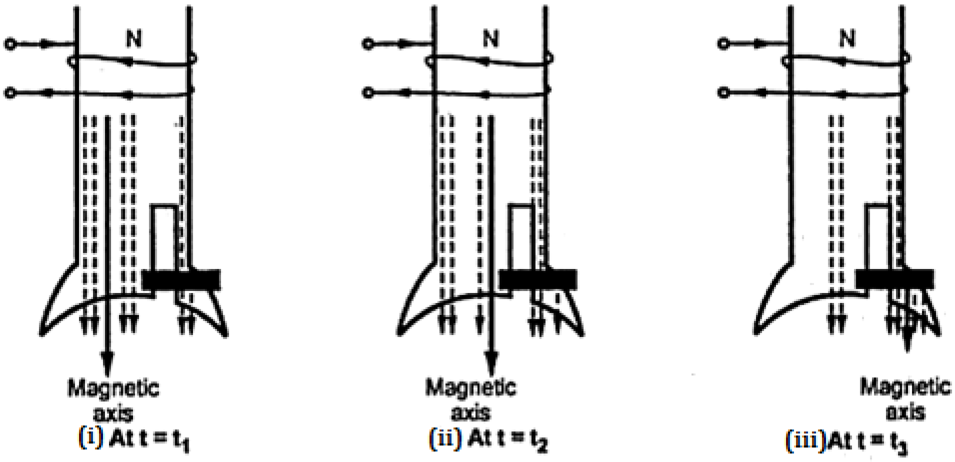
The current carried by the stator winding is alternating and produces alternating flux. The waveform of the flux is shown in the below figure. The distribution of this flux in the pole area is greatly influenced by the role of copper shading band. Consider the three instants say t_1, t_2 and t_3 during first half cycle of the flux as shown, in the figure.



Waveform of stator flux

Case (i) $t=t_1$

At instant $t = t_1$, rate of rise of current and hence the flux is very high. Due to the transformer action, large e.m.f. gets induced in the copper shading band. This circulates current through shading band as it is short circuited, producing its own flux. According to ***Lenz's law,*** the direction of this current is so as to oppose the cause i.e. rise in current. Hence shading ring flux is opposing to the main flux. Hence there is crowding of flux in non-shaded part while weakening of flux in shaded part. Overall magnetic axis shifts in non-shaded part as shown in the below figure (i).



(i) At $t = t_1$ (ii) At $t = t_2$ (iii) At $t = t_3$

Production of rotating magnetic field

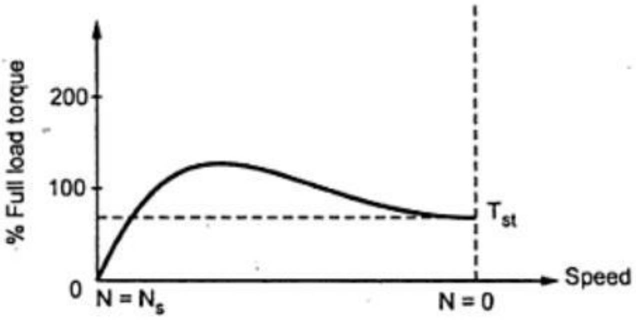
Case (ii) $t=t_2$

At instant $t = t_2$, rate of rise of current and hence the rate of change of flux is almost zero as flux almost reaches to its maximum value. So $d\Phi/dt = 0$. Hence there is very little induced e.m.f. in the shading ring. Hence the shading ring flux is also negligible, hardly affecting the distribution of the main flux. Hence the main flux distribution is uniform and magnetic axis lies at the centre of the pole face as shown in the figure (ii).

Case (iii) $t=t_3$

At the instant $t = t_3$, the current and the flux is decreasing. The rate of decrease is high which again induces a very large e.m.f. in the shading ring. This circulates current through the ring which produces its own flux. Now direction of the flux produced by the shaded ring current is so as to oppose the cause which is decrease in flux. So it oppose the decrease in flux means its direction is same as that of main flux, strengthening it. So there is crowding of flux in the shaded part as compared to non-shaded part. Due to this the magnetic axis shifts to the middle of the shaded part of the pole. This is shown in the figure (iii).

This sequence keeps on repeating for negative half cycle too. Consequently this produces an effect of rotating magnetic field, the direction of which is from non-shaded part of the pole to the shaded part of the pole. Due to this, motor produces the starting torque is low which is about 40 to 50% of the full load torque for this type of motor. The torque speed characteristics are shown in the below figure.



Torque-speed characteristics of shaded pole motor

Due to absence of centrifugal switch the construction is simple and robust but this type of motor has a lot of lamination as:

- The starting torque is poor.
- The power factor is very low.

- Due to I^2R, copper losses in the shading ring the efficiency are very low.
- The speed reversal is very difficult. To achieve the speed reversal, the additional set of shading rings is required. By opening one set and closing other, direction can be reversed but the method is complicated and expensive.
- The size and power rating of these motors is very small. These motors are usually available in a range of 1/300 to 1/20 kW.
- These motors are cheap but have very low starting torque, low power factor and low efficiency

Application

- Advertising displays,
- Film projectors,
- Record players,
- Gramophones,
- Hair dryers,
- Photo copying machines

16. Explain construction and operation of stepper motor. (NOV/2013)

(or)

Explain in detail about different modes of operation of stepper motor. (NOV/2012)

STEPPER MOTOR

A step or stepping motor converts electronic pulses into proportionate mechanical movement. Each revolution of the stepper motor's shaft is made up of a series of discrete individual steps. A step is defined as the angular rotation produced by the output shaft each time the motor receives a step pulse. These types of motors are very popular in digital control circuits, such as robotics, because they are ideally suited for receiving digital pulses for step control. Each step causes the shaft to rotate a certain number of degrees.

A step angle represents the rotation of the output shaft caused by each step, measured in degrees. The below figure illustrates a simple application for a stepper motor. Each time the controller receives an input signal, the paper is driven a certain incremental distance. In addition to the paper drive mechanism in a printer, stepper motors are also popular in machine tools, process control systems, tape and disk drive systems, and programmable controllers.

Stepper Motors Working

Stepper motors consist of rotating shaft with permanent magnet attached is called rotor and the stationary housing containing the coil-wound poles is called stator (i.e. electromagnets on the stationary portion that surrounds the motor).

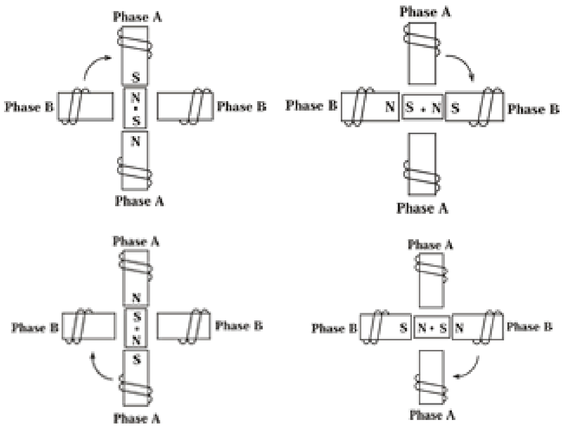
Types of Stepper Motors

There are basically three types of stepping motors;

- Variable reluctance stepper motor
- Permanent magnet stepper motor
- Hybrid stepper motor

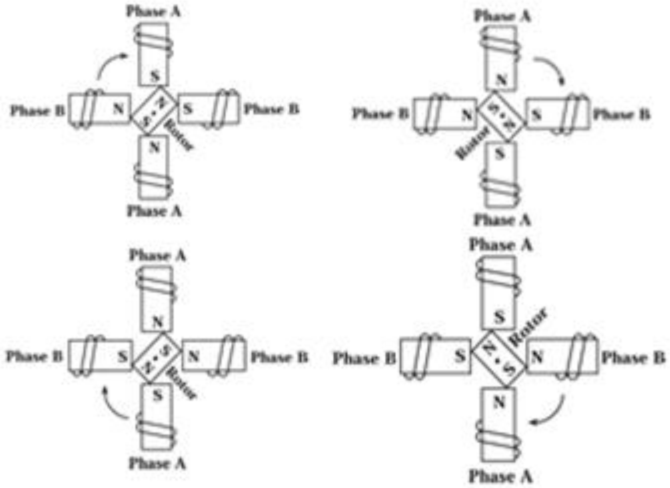
Full Stepping

The below figure illustrates a typical step sequence for a two phase motor. In Step 1 phase A of a two phase stator is energized. This magnetically locks the rotor in the position shown, since unlike poles attract. When phase A is turned off and phase B is turned on, the rotor rotates 90° clockwise. In Step 3, phase B is turned off and phase A is turned on but with the polarity reversed from Step 1. This causes another 90° rotation. In Step 4, phase A is turned off and phase B is turned on, with polarity reversed from Step 2. Repeating this sequence causes the rotor to rotate clockwise in 90° steps.



One Phase ON

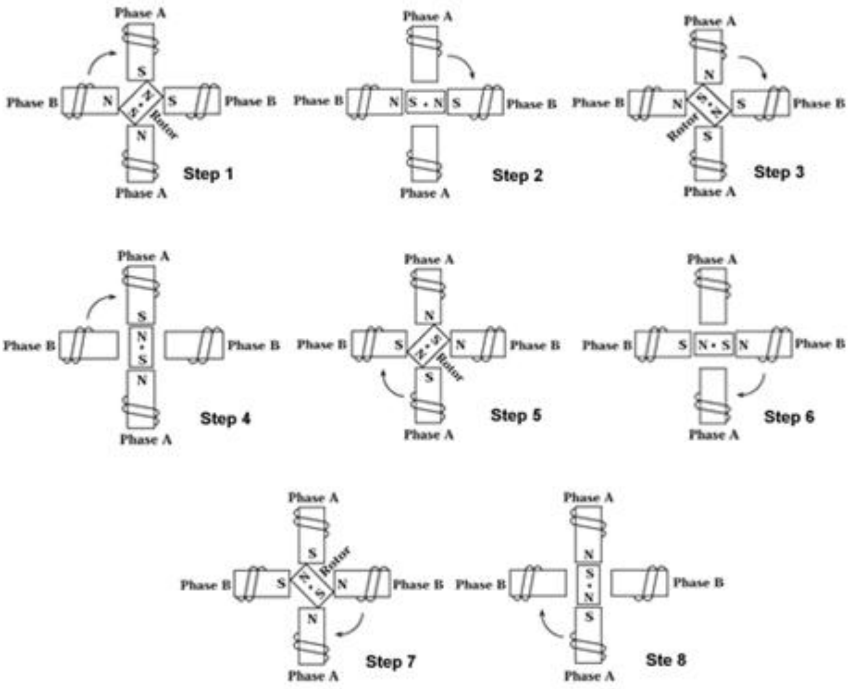
The stepping sequence illustrated in the above figure is called “one phase on” stepping. A more common method of stepping is “two phase on” where both phases of the motor are always energized. However, only the polarity of one phase is switched at a time, as shown in figure With two phases on stepping the rotor aligns itself between the “average” north and “average” south magnetic poles. Since both phases are always on, this method gives 41.4% more torque than “one phase on” stepping, but with twice the power input.



Two Phase ON

Half Stepping

The motor can also be “half stepped” by inserting an off state between transitioning phases. This cuts a stepper’s full step angle in half. For example, a 90° stepping motor would move 45° on each half step, in the below figure. However, half stepping typically results in a 15% - 30% loss of torque depending on step rate when compared to the two phase on stepping sequence. Since one of the windings is not energized during each alternating half step there is less electromagnetic force exerted on the rotor resulting in a net loss of torque.



Half Stepping

There are several types of stepper motors. 4-wire stepper motors contain only two electromagnets; however the operation is more complicated than those with three or four magnets, because the driving circuit must be able to reverse the current after each step. For our purposes, we will be using a 6-wire motor.

Unlike our example motors which rotated 90 degrees per step, real-world motors employ a series of mini-poles on the stator and rotor to increase resolution. Although this may seem to add more complexity to the process of driving the motors, the operation is identical to the simple 90 degree motor we used in our example. An example of a multi pole motor can be seen in the below figure. In position 1, the north pole of the rotor's permanent magnet is aligned with the south pole of the stator's electromagnet. Note that multiple positions are aligned at once. In position 2, the upper electromagnet is deactivated and the next one to its immediate left is activated, causing the rotor to rotate a precise amount of degrees. After eight steps the sequence repeats

17. Explain the construction and working of AC series motor. (APRIL/2013) (APRIL/2012)

SINGLE PHASE A.C. SERIES MOTOR

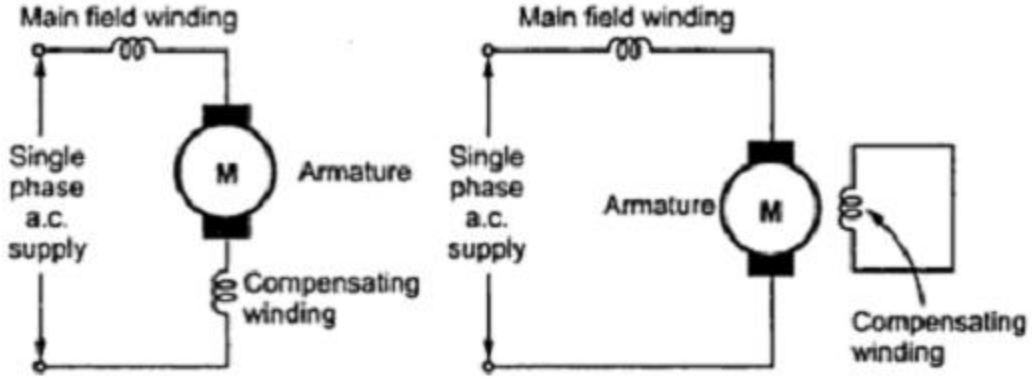
In a normal DC motor if direction of both field and armature current is reversed, the direction of torque remains unchanged. So when normal DC series motor is connected to an AC supply, both field and armature current get reversed and unidirectional torque gets produced in the motor hence motor can work on AC. supply. But performance of such motor is not satisfactory due to the following reasons

- There are tremendous eddy current losses in the yoke and field cores, which causes overheating.
- Armature and field winding offer high reactance to AC due to which operating power factor is very low.
- The sparking at brushes is a major problem because of high voltage and current induced in the short circuited armature coils during the commutation period.

Some modifications are required to have the satisfactory performance of DC series motor on AC supply, when it is called AC series motor. The modification are:

- To reduce the eddy current losses, yoke and pole core construction is laminated.
- The power factor can be improved by reducing the magnitudes of field and armature reactance.

Field reactance can be decreased by reducing the number of turns. But this reduces the field flux. But this reduction in flux (N α 1/Φ), increases the speed and reduce the torque. To keep the torque same it is necessary to increase the armature turns proportionately. This increases the armature inductance. Now to compensate for increased armature flux which produce severe armature reaction, it is necessary to use compensating winding. The flux produced by this winding is opposite to that produced by armature and effectively neutralizes the armature reaction. If such a compensating winding is connected in series with the armature, the motor is said to be 'conductively compensated'. For motors to be operated on AC and DC both, the compensation should be conductive. If compensating winding is short circuited on its self, the motor is said to be 'inductively compensated'. In this compensating winding acts as a secondary of transformer and armature as its primary. The ampere turns produced by compensating winding neutralise the armature ampere turns.



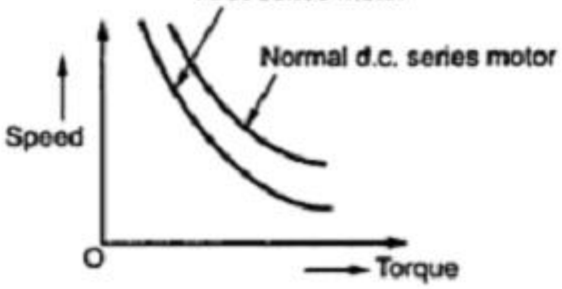
(a) **(b)**

(a)Conductively Compensated motor, (b) Inductively Compensated Motor

To reduce the induced e.m.f. due to transformer action in the armature coils while commutation period, the following measures are taken:

- The flux per pole is reduced and numbers of poles are increased.
- The frequency of supply used is reduced.
- Preferably single turn armature coils are used.

The characteristics of such motor are similar to that of DC series motor. The torque varies as square of the armature current and speed varies inversely as the armature current. The speed of such motor can be dangerously high on no load condition and hence it is always started with some load. Starting torque produced is high which the full load torque is 3 to 4 times. The speed-torque characteristics of such type of motors is as shown in the Figure



Torque Speed Characteristics

Applications

- Because of high starting torque it is used in electric traction
- Hoists
- Locomotives

Reference:

- *B. L. Theraja & A. K. Theraja, A Textbook of Electrical Technology: AC and DC Machines, Volume - II, 23rd Edition, S. Chand & Company, New Delhi, 2012*
- *U. A. Bakshi, M. V. Bakshi, Electrical Machines-II, Second Edition, Technical Publications*

3. ALTERNATOR

Alternators - construction - Operating principle - alternators on No load – Alternators on Load - Phasor diagram - Losses – Efficiency-voltage regulation by EMF method – Parallel operation of alternators

Part- A (2 Marks)

1. **Write down the equation for frequency of emf induced in an alternator** (NOV/2014)

Frequency of emf induced in an Alternator, f, expressed in cycles per second or Hz, is given by the following equation

F = (PN) / 120 Hz,

Where P- Number of poles

N-Speed in rpm

2. **Name the types of alternator based on their rotor construction**(NOV/2014)

Based on the alternator rotor construction

- Salient pole (or) Projected pole type
- Non- salient Pole (or) Smooth Cylindrical type

3. **Calculate the synchronous speed of a four pole 50Hz alternator.**(APRIL/2014)

$$\mathrm{N}_s = \frac{120\ \mathrm{f}}{\mathrm{P}}$$

$$\mathrm{N}_s = \frac{120 * 50}{4}$$

$$\mathbf{N}_{\boldsymbol{s}} = \mathbf{1500}\ \boldsymbol{rpm}$$

4. **Write the emf equation of an alternator.(** APRIL/2014)

$$\mathbf{E_{ph}} = \mathbf{4.44\ K}_{\boldsymbol{C}}\mathbf{K}_{\boldsymbol{d}}\ \boldsymbol{f}\ \boldsymbol{\Phi}\mathbf{T_{ph}}\text{volts}$$

Where , K_c =Pitch factor

K_d = Distribution factor

5. **Differentiate salient pole rotor and smooth cylindrical type rotor of an alternator**(NOV/2013)(APRIL/2012)

Salient Pole Rotor	Cylindrical Rotor
Large diameter and short axial length	Small diameter and long axial length
Used for low speed alternators	Used for high - speed turbo-alternators
Has projecting poles	No projecting poles
Needs damper windings	Does not need damper windings
Windage loss is more	Windage loss is less

6. **List the various losses in an alternator**(NOV/2013)(or) **What are the losses in an alternator?**(NOV/2012)

The various losses occur in an alternators are

- Iron loss
    - Hysteresis loss
    - Eddy current loss
- Mechanical loss
    - Frictional loss
    - Windage loss

Constant losses

- Copper loss (or) Variable Loss

7. **Define voltage regulation.**(APRIL/2013)(or)**Define voltage regulation of an alternator.**(APRIL/2012)

The voltage regulation of an alternator is defined as the change in its terminal voltage when full load is removed, keeping field excitation and speed constant, divided by the rated terminal voltage.

So if V_{ph}=Rated terminal voltage

E_{ph}=No load induced e.m.f.

The voltage regulation is defined as,

$$Regulation\,\% = \frac{E\,ph - Vph}{Vph} X\ 100$$

8. **What is meant by synchronous reactance?** (NOV/2012)

It is the sum of the leakage reactance X1 and armature reactance Xa.

$$X_s = X_1 + X_a$$

9. **Why emf method called Pessimistic method?**

The value of voltage regulation obtained by EMF method is always more than the actual value; therefore it is called Pessimistic method

10. **Why are Alternators rated in kVA and not in kW?**

The continuous power rating of any machine is generally defined as the power the machine or apparatus can deliver for a continuous period so that the losses incurred in the machine gives rise to a steady temperature rise not exceeding the limit prescribed by the insulation class. Apart from the constant loss incurred in Alternators is the copper loss, occurring in the three phase winding which depends on I^2R, the square of the current delivered by the generator. As the current is directly related to apparent – power delivered by the generator, the Alternators have only their apparent power in VA/kVA/MVA as their power rating.

11. **What is the necessity for predetermination of voltage regulation?**

Most of the alternators are manufactured with large power rating and large voltage ratings. Conduction load test is not possible for such alternators. Hence other indirect methods of testing are used and the performance can be predetermined at any desired load currents and power factors.

12. What are the main parts of Alternator?

- Stator core
- Salient or non salient rotor field winding
- Rotor shaft
- Bearings
- Internal cooling Fan etc.

13. Write down conditions for parallel operation of two Alternators?

Both the Alternator should have same

- Voltage
- Frequency
- Phase sequence of three phase supply

Part –B (11 Marks)

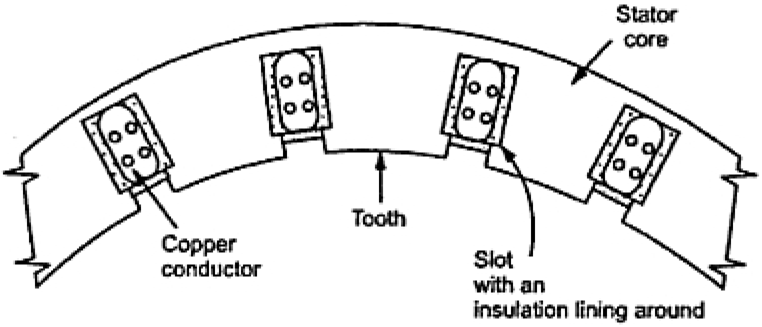
1. Write in details about the construction and working of an alternator?

Construction of Synchronous Generator

Most of the alternators prefer rotating field type of the construction. In case of alternators the winding terminology is slightly different than in case of DC generators. In alternators the stationary winding is called 'Stator' while the rotating winding is called 'Rotor'.

Stator

The stator is a stationary armature. This consists of a core and the slots to hold the armature winding similar to the armature of a DC generator. The stator core uses a laminated construction. It is built up of special steel stampings insulated from each other with varnish or paper. The laminated construction is basically to keep down eddy current losses. Generally choice of material is steel to keep down hysteresis losses.



Section of an alternator stator

The entire core is fabricated in a frame made of steel plates. The core has slots on its periphery for housing the armature conductors. Frame does not carry any flux and serves as the support to the core. Ventilation is maintained with the help of holes cast in the frame. The section of an alternators stator is shown in the above figure.

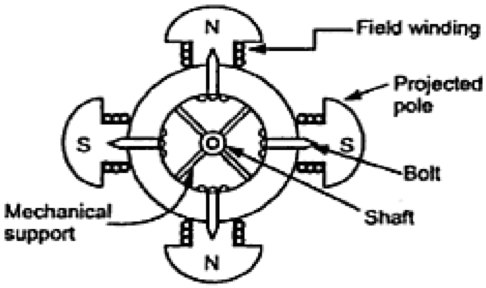
Rotor:

There are two types of rotors used in alternators,

- Salient pole type
- Smooth cylindrical type.

Salient Pole Type

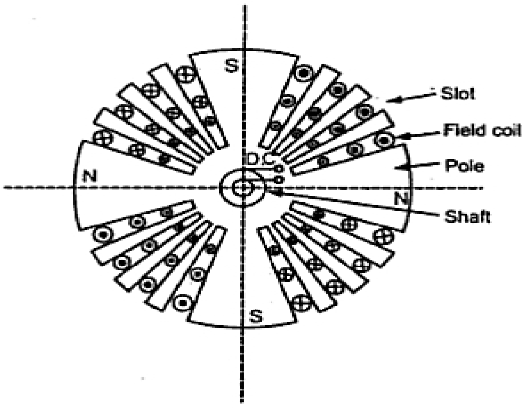
This is also called projected pole type as all the poles are projected out from the surface of the rotor. The poles are built up of thick steel laminations. The poles are bolted to the rotor as shown in the Figure. The pole face has been given a specific shape. The field winding is provided on the pole shoe. These rotors have large diameter and small axial length. The limiting factor for the size of the rotor is the centrifugal force acting on the rotating member of the machine. As mechanical strength of salient pole type is less, this is preferred for low speed alternators ranging from 125 r.p.m. to 500 r.p.m. The prime movers used to drive such rotor are generally water turbines and I.C. engines.



Salient pole type rotor

Smooth Cylindrical Type

This is also called non-salient type or non-projected pole type or round rotor construction. The below figure shows smooth cylindrical type of rotor.



Smooth cylindrical rotor

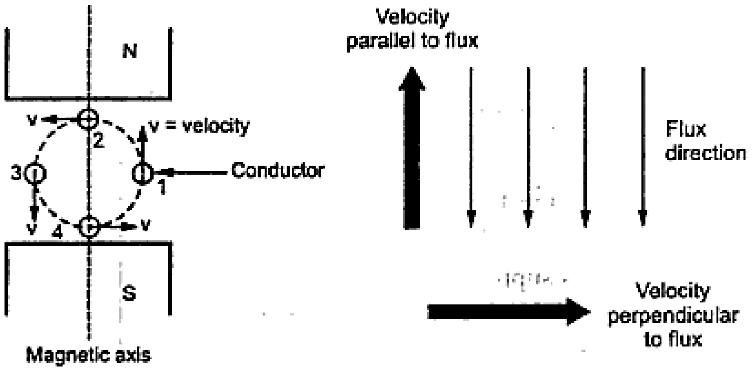
The rotor consists of small solid steel cylinder, having number of slots to accommodate the field coil. The slots are covered at the top with the help of steel or manganese wedges. The unslotted portions of the cylinder itself act as the poles. The poles are not projecting out and the surface of the rotor is smooth which maintains uniform air gap between stator and the rotor. These rotors have small diameters and large axial lengths. This is to keep peripheral speed within limits. The main advantage of this type is that these are mechanically very strong and thus preferred for high speed alternators ranging between 1500 to 3000 r.p.m. Such high speed alternators are called 'turbo alternators'. The prime movers used to drive such type of rotors are generally steam turbines, electric motors.

Working Principle of Synchronous Generator

The alternators work on the principle of electromagnetic induction. When there is a relative motion between the conductors and the flux, e.m.f. gets induced in the conductors. The DC generators also work on the same principle. The only difference in practical alternator and a DC generator is that in an alternator the conductors are stationary and field is rotating. But for understanding purpose we can always consider relative motion of conductors with respect to the flux produced by the field winding.

Consider a relative motion of a single conductor under the magnetic field produced by two stationary poles. The magnetic axis of the two poles produced by field is vertical, shown dotted in the below Figure.

Let conductor starts rotating from position 1. At this instant, the entire velocity component is parallel to the flux lines. Hence there is no cutting of flux lines by the conductor. So $d\Phi/dt$ at this instant is zero and hence induced e.m.f. in the conductor is also zero.



Two pole alternator

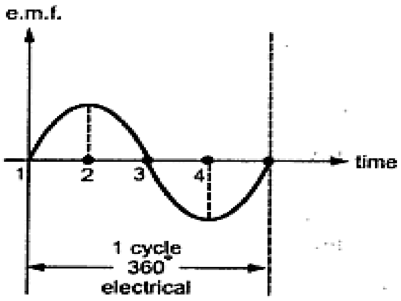
As the conductor moves from position 1 towards position 2, the part of the velocity component becomes perpendicular to the flux lines and proportional to that, e.m.f. gets induced in the conductor. The magnitude of such an induced e.m.f. increases as the conductor moves from position 1 towards 2.

At position 2, the entire velocity component is perpendicular to the flux lines. Hence there exists maximum cutting of the flux lines. And at this instant, the induced e.m.f. in the conductor is at its maximum.

As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing and hence induced e.m.f. magnitude also starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced e.m.f. in the conductor is zero.

As the conductor moves from 3 towards 4, the velocity component perpendicular to the flux lines again starts increasing. But the direction of velocity component now is opposite to the direction of velocity component existing during the movement of the conductor from position 1 to 2. Hence an induced e.m.f. in the conductor increases but in the opposite direction.

At position 4, it achieves maxima in the opposite direction, as the entire velocity component becomes perpendicular to the flux lines. Again from position 4 to 1, induced e.m.f. decreased and finally at position 1, again becomes zero. This cycle continues as conductor rotates at a certain speed. So if we plot the magnitudes of the induced e.m.f. against the time, we get an alternating nature of the induced e.m.f. as shown in the Fig.This is the working principle of an alternator



Alternating nature of the induced e.m.f

2. Explain about the winging terminology used in alternator and brief its types

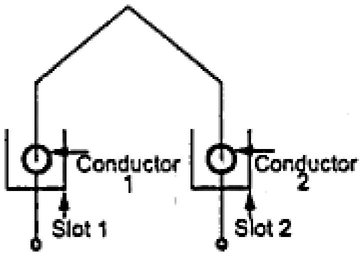
Armature Winding of Synchronous Generator

Armature winding of alternators is different from that of DC machines. Basically three phase alternators carry three sets of windings arranged in the slots in such a way that there exists a phase difference of 120^0 between the induced e.m.f. in them. In a DC machine, winding is brought out. In three phase alternators winding is open i.e. two ends of each of set of winding is brought out. In three phase alternators, the six terminals are brought out which are finally connected in star or delta and then the three terminals are brought out. Each set of windings represents winding per phase and induced e.m.f. in each set is called induced e.m.f. per phase denoted as E_{ph}. All the coils used for one phase must be connected in such a way that their e.m.f helps each other. And overall design should be in such a way that the waveform of an induced e.m.f. is almost sinusoidal in nature.

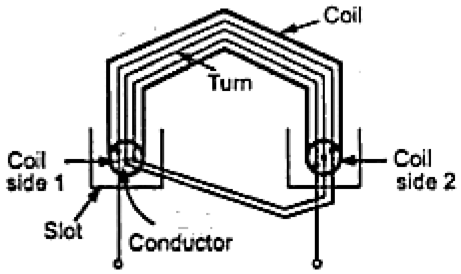
Winding Terminology

1) Conductor: The part of the wire, which is under the influence of the magnetic field and responsible for the induced e.m.f. is called active length of the conductor. The conductors are placed in the armature slots.

2) Turn: A conductor in one slot, when connected to a conductor in another slot forms a turn. So two conductors constitute a turn. This is shown in the Fig. (a).



(a)Turn



(b)Multiturn coil

3) Coil: As there are number of turns, for simplicity the number of turns are grouped together to form a coil. Such a coil is called multiturn coil. A coil may consist of single turn coil. The Fig. (b) shows a multiturn coil.

4) Coil side: Coil consists of many turns. Part of the coil in each slot is called coil side of a coil as shown in the Fig. (b).

5) Pole Pitch: It is centre to centre distance between the two adjacent poles. We have seen that for one rotation of the conductors, 2 poles are responsible for 360^0 electrical of e.m.f., 4 poles are responsible for 720^0 electrical of e.m.f. and so on. So 1 pole is responsible for 180^0 electrical of induced e.m.f. So 180^0 electrical is also called one pole pitch. Practically how many slots are under one pole which are responsible for 180^0 electrical, are measured to specify the pole pitch. e.g. Consider 2 pole, 18 slots armature of an alternator. Then under 1 pole there are 18/2 i.e. 9 slots. So pole pitch is 9 slots or 180^0 electrical. This means 9 slots are responsible to produce a phase difference of 180 between the e.m.f. induced in different conductors.

This number of slots/poles is denoted as 'n'.

Pole pitch = 180^0 electrical
= slots per pole (no. of slots/P) =n

6) Slot angle (β): The phase difference contributed by one slot in degrees electrical is called slot angle β.

As slots per pole contributes 180^o electrical which is denoted as 'n', we can write,

1 slot angle = $180^o/n$

$$\beta = \frac{180^0}{n}$$

In the above example, n = 18/2 = 9, while $\beta = 180^o/n = 20^o$

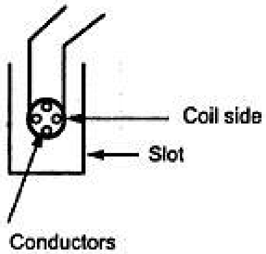
Types of Armature Windings:

In general armature winding is classified as,

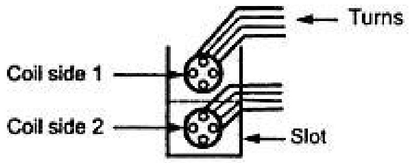
- Single layer and double layer winding.
- Full pitch and short pitch winding.
- Concentrated and distributed winding.

1. Single Layer and Double Layer Winding

If a slot consists of only one coil side, winding is said to be single layer. This is shown in the Fig. (a). While there are two coil sides per slot, one at the bottom and one at the top the winding is called double layer as shown in the Fig. (b).



(a) Single layer



(b) Double layer

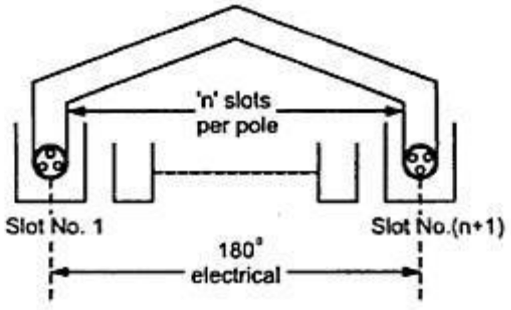
A lot of space gets wasted in single layer hence in practice generally double layer winding is preferred.

2. Full Pitch and Short Pitch Winding

As seen earlier, one pole pitch is electrical. The value of 'n', slots per pole indicates how many slots are contributing electrical phase difference. So if coil side in one slot is connected to a coil side in another slot which is one pole pitch distance away from first slot, the winding is said to be full pitch winding and coil is called full pitch coil.

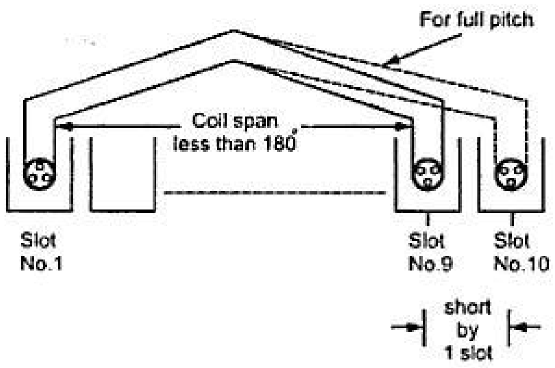
Coil Span

It is the distance on the periphery of the armature between two coil sides of a coil. It is usually expressed in terms of number of slots or degrees electrical. So if coil span is 'n' slots or 180^0 electrical the coil is called full pitch coil.



Full Pitch Coil

As against this if coils are is slightly less than a pole pitch i.e. less than 180 electrical, the coils are called, short pitched coils or fractional pitched coils. Generally coils are shorted by one or two slots. So in 18 slots, 2 pole alternator instead of connecting a coil side in slot No. 1 to slot No.10, it is connected to a coil side in slot No.9 or slot No. 8, coil is said to be short pitched coil and winding is called short pitch winding. This is shown in the below figure.



Short Pitch Coil

Advantages of Short Pitch Coils

In actual practice, short pitch coils are used as it has following advantages,

- The length required for the end connections of coils is less i.e. inactive length of winding is less. So less copper is required. Hence this is economical.
- Short pitching eliminates high frequency harmonics which distort the sinusoidal nature of e.m.f. Hence waveform of an induced e.m.f. is more sinusoidal due to short pitching.
- As high frequency harmonics get eliminated, eddy current and hysteresis losses which depend on frequency also get minimized. This increases the efficiency.

3. Concentrated and Distributed Winding

In three phase alternators, we have seen that there are three different sets of windings, each for a phase. So depending upon the total number of slots and number of poles, we have certain slots per phase available under each pole. This is denoted as 'm'.

m = Slots per pole per phase = n/number of phases

= n/3 (generally no. of phases is 3)

For example in 18 slots, 2 pole alternator we

have, n = 18/2 = 9 and m = 9/3 = 3

So we have 3 slots per pole per phase available. Now let 'x' number of conductors per phase are to be placed under one pole. And we have 3 slots per pole per phase available. But if all 'x' conductors per phase are placed in one slot keeping remaining 2 slots per pole per phase empty then the winding is called **concentrated winding.** So in concentrated winding all conductors or coils belonging to a phase are placed in one slot under every pole.

But in practice, an attempt is always made to use all the 'm' slots per pole per phase available for distribution of the winding. So if 'x' conductors per phase are distributed amongst the 3 slots per phase available under every pole, the winding is called **distributed winding.** So in distributed type of winding all the coils belonging to a phase are well distributed over the 'm' slots per phase, under every pole. Distributed winding makes the waveform of the induced e.m.f. more sinusoidal in nature. Also in concentrated winding due to large number of conductors per slot, heat dissipation is poor. So in practice, double layer, short pitched and distributed type of armature winding is preferred for the alternators

3. Derive an expression for the induced EMF of an alternator. (APRIL/2013)

E.M.F. Equation of an Alternator:

Let Φ = Flux per pole, in Wb

P =Number of poles

N_S=Synchronous speed in r.p.m.
f =Frequency of induced e.m.f. in Hz
Z =Total number of conductors
Z_{ph}=Conductors per phase connected in series
Z_{ph}=Z/3 as number of phases =3.

Consider a single conductor placed in a slot.

The average value of emf induced in a conductor =$\frac{d\varphi}{dt}$

For one revolution of a conductor,

$$e_{avg}\ per\ conductor = \frac{flux\ cut\ in\ one\ revolution}{time\ taken\ for\ one\ revolution}$$

Total flux cut in one revolution = φ * P

Time taken for one revolution = $\frac{60}{N_S}$ $seconds$

$$= \frac{\varphi\ P}{\left(\frac{60}{N_S}\right)} = \frac{\varphi\ P\ N_S}{60}$$

But $f = \frac{P\ N_S}{120}$

Substituting in (1),

$$e_{avg}\ \text{per conductor} = 2f\ \phi\ \text{volts}$$

Assume full pitch winding for simplicity i.e. this conductor is connected to a conductor which is 180^{o} electrical apart. So there two e.m.f.s will try to setup a current in the same direction i.e. the two e.m.f. are helping each other and hence resultant e.m.f. per turn will be twice the e.m.f. induced in a conductor.

∴ e.m.f. per turn =2×(e.m.f. per conductor)

=2× (2 f Φ) = 4fΦ volts

Let T_{ph} be the total number of turn per phase connected in series. Assuming concentrated winding, we can say that all are placed in single slot per pole per phase. So induced e.m.f.s in all turns will be in phase as placed in single slot. Hence net e.m.f. per phase will be algebraic sum of the e.m.f.s per turn.

Average E_{ph}=T_{ph}×(Average e.m.f. per turn)

Average Eph= T_{ph}×4 f Φ

But in AC. circuits R.M.S. value of an alternating quantity is used for the analysis. The form factor is 1.11 of sinusoidal e.m.f.

$$K_f = \frac{\text{R.M.S.}}{\text{Average}} = 1.11 \qquad \text{for sinusoidal}$$

∴ R.M.S. value of E_{ph}=K ×Average value

E_{ph}=1.11 ×4 f Φ T_{ph}volts

E_{ph}=4.44 f ΦT_{ph}volts .... (2)

This is the basic e.m.f. equation for an induced e.m.f. per phase for full pitch, concentrated type of winding.

Where T_{ph}=Number of turns per phase

$T_{ph}=Z_{ph}/2$ .... as 2 conductors constitute 1 turn

But as mentioned earlier, the winding used for the alternators is distributed and short pitch hence e.m.f. induced slightly gets affected.

Generalized Expression for E.M.F. Equation of an Alternator

Considering full pitch, concentrated winding.

$E_{ph}=4.44\ f\ \Phi\ T_{ph}$ Volts.

But due to short pitch, distributed winding used in practice, this will reduce by factors and so generalised expression for e.m.f. equation can be written as

$$\mathbf{E_{ph} = 4.44\ K_C K_d\ \mathit{f}\ \Phi T_{ph}} \text{ volts}$$

Where,

$$K_c = \cos\left(\frac{\alpha}{2}\right)$$

$$K_d = \frac{Sin\left(\frac{m\beta}{2}\right)}{m\ Sin\left(\frac{\beta}{2}\right)}$$

For full pitch coil, K_C =1

For concentrated winding, K_d =1

Pitch Factor or Coil Span Factor (Kc)

The factor by which, induced e.m.f. gets reduced due to short pitching is called **pitch factor or coil span factor** denoted by K_C. It is defined as the ratio of resultant e.m.f. when coil is short pitch to the resultant e.m.f. when coil is full pitched. It is always less than one.

$$\boxed{K_c = \cos\left(\frac{\alpha}{2}\right)}$$

Where, α=Angle of short pitch

Distribution Factor (Kd)

The factor by which there is a reduction in the e.m.f. due to distribution of coils is called **distribution factor** denoted as K_d.

The distribution factor is defined as the ratio of the resultant e.m.f. when coils are distributed to the resultant e.m.f. when coils are concentrated. It is always less than one.

$$\boxed{K_d = \frac{Sin\left(\frac{m\beta}{2}\right)}{m\ Sin\left(\frac{\beta}{2}\right)}}$$

Where, m = slots per pole per phase
β = slot angle
n = slot per pole

Effect of Chording

The e.m.f. generated in the winding is proportional to cos (x/2) where is angle of chording and x is order of harmonic. If proper value of angle of chording is selected then harmonic e.m.f.s can be reduced significantly.

4. Explain in detail about armature reaction in alternator and also state voltage regulation?

ARMATURE REACTION AND VOLATGE REGULATION

The voltage regulation of an alternator is defined as the change in its terminal voltage when full load is removed, keeping field excitation and speed constant, divided by the rated terminal voltage.

So if, V_{ph} = Rated terminal voltage

E_{ph} = No load induced e.m.f.

The voltage regulation is defined as,

$$\boxed{Regulation\,\% = \frac{E\,ph - Vph}{Vph} X\ 100}$$

As long as the alternator terminals are open (i.e), no load is connected to an alternator, the induced e.m.f is same as the voltage available at the terminals. Thus terminal voltage per phase V_{ph} and induced e.m.f per phase E_{ph} are same as long as alternator is on no load. But when the alternator is loaded, the armature of an alternator carries current. We know that, any current carrying conductor produces its own flux. Hence on load, armature of an alternator produces its own flux called armature flux. This flux has significant effect on the performance of an alternator on load. The terminal voltage V_{ph} no longer remains same as induced e.m.f E_{ph} on load conditions. The performance of an alternator on load is mathematically expressed by a parameter called voltage regulation.

Parameters of Armature Winding

There are three important parameters of an armature winding of an alternator. These are,

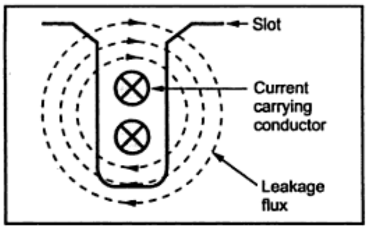
1. Armature resistance R_a
2. Armature leakage reactance X_L
3. Reactance corresponding to armature reaction

1. Armature Resistance

Every armature winding has its own resistance. The effective resistance of an armature winding per phase is denoted as R_a Ω/ph. Generally the armature resistance is measured by applying the known DC voltage and measuring the D.C. Current through it. The ratio of applied voltage and measured current is the armature resistance. Generally the effective armature resistance under A.C. conditions is taken 1.25 to 1.75 times the D.C. resistance.

2. Armature Leakage Reactance

When armature carries a current, it produces its own flux. Some part of this flux completes its path through the air around the conductors itself. Such a flux is called leakage flux. This is shown in the Fig.



Note: This leakage flux makes the armature winding inductive in nature. So winding possesses a leakage reactance, in addition to the resistance.

So if 'L' is the leakage inductance of the armature winding per phase, then leakage reactance per phase is given by $X_L = 2\pi f L$ Ω/ph. The value of leakage reactance is much higher than the armature resistance. Similar to the DC machines, the value of armature resistance is very very small.

3. Armature Reaction

When the load is connected to the alternator, the armature winding of the alternator carries a current. Every current carrying conductor produces its own flux so armature of the alternator also produces its own flux, when carrying a current. So there are two fluxes present in the air gap, one due to armature current while second is produced by the filed winding called main flux. The flux produced by the armature is called armature flux. So effect of the armature flux on the main flux affecting its value and the distribution is called **armature reaction.**

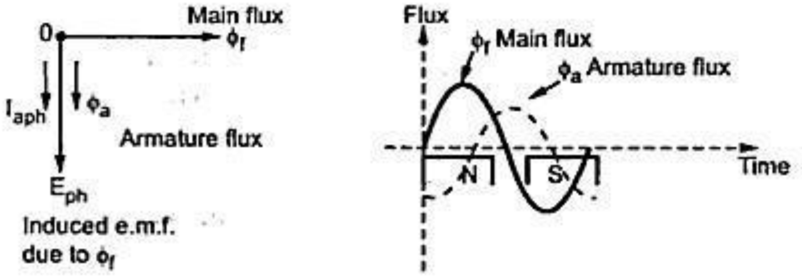
The effect of the armature flux not only depends on the magnitude of the current flowing through the armature winding but also depends on the nature of the power factor of the load connected to the alternator.

Effect of nature of the load power factor on the armature reaction

1.Unity Power Factor Load

Consider a purely resistive load connected to the alternator, having unity power factor. As induced e.m.f. E_{ph} drives a current of I_{aph} and load power factor is unity, E_{ph} and I_{ph} are in phase with each other.

If Φ_f is the main flux produced by the field winding responsible for producing E_{ph} then E_{ph} lags Φ_f by 90^0. Now current through armature I_a, produces the armature flux say Φ_a. So flux Φ_a and I_a are always in the same direction. This relation between Φ_f , Φ_a, E_{ph} and I_{aph} can be shown in the phasor diagram. (See Fig.)



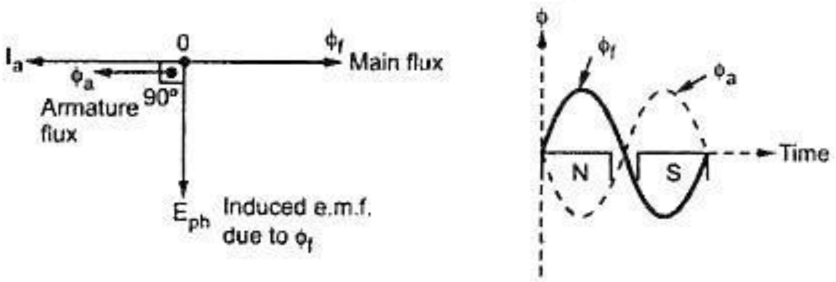
Armature reaction for unity power factor

It can be seen from the phasor diagram that there exists a phase difference of 90^0 between the armature flux and the main flux. The waveforms for the two fluxes are also shown in the Fig. 1. From the waveforms it can be seen that the two fluxes oppose each other on the left half of each pole while assist each other on the right half of each pole. Hence average flux in the air gap remains constant but its distribution gets distorted. Hence such distorting effect of armature reaction under unity p.f. condition of the load is called cross **magnetising effect** of armature reaction. Due to such distortion of the flux, there is small drop in the terminal voltage of the alternator.

2. Zero Lagging Power Factor Load

Consider a purely inductive load connected to the alternator having zero lagging power factors. This indicates that I_{aph} driven by E_{ph} lags E_{ph} by 90^0 which is the power factor angle Φ. Induced e.m.f. E_{ph} lags main flux Φ_f by 90^0 while Φ_a is in the same direction as that of I_a. So the phasor diagram and the waveforms are shown in the Fig. It can be seen from the phasor diagram that the armature flux and the main flux are exactly in opposite direction to each other. So armature flux tries to cancel the main flux. Such an effect of armature reaction is called **demagnetising effect** of the armature reaction.

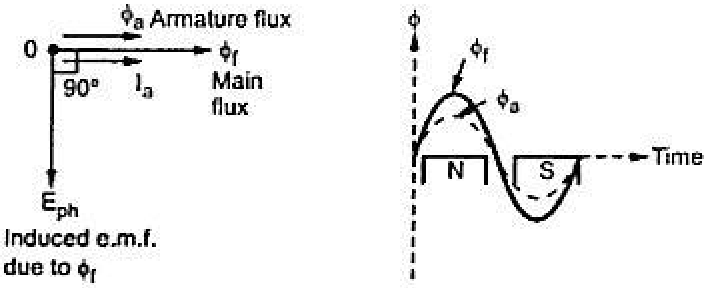
As this effect causes reduction in the main flux, the terminal voltage drops. This drop in the terminal voltage is more than the drop corresponding to the unity p.f. load.



Armature reaction for zero lagging p.f. load

3. Zero Leading Power Factor Load

Consider a purely capacitive load connected to the alternator having zero leading power factor. This means that armature current I_{aph} driven by E_{ph}, leads E_{ph} by 90^0, which is the power factor angle Φ. Induced e.m.f. E_{ph} lags Φ_f by 90^0 while I_{aph} and Φ_a are always in the same direction. The phasor diagram and the waveforms are shown in the Fig.



Armature reaction for zero leading p.f. load

It can be seen from the phasor diagram and waveforms shown in the Fig, the armature flux and the main field flux are in the same direction i.e. they are helping each other. This results into the addition in main flux. Such an effect of armature reaction due to which armature flux assists field flux is called **magnetising effect** of the armature reaction.

As this effect adds the flux to the main flux, greater e.m.f. gets induced in the armature. Hence there is increase in the terminal voltage for leading power factor loads.

5. Draw and explain the phasor diagram of a loaded alternator. (APRIL/2014)(or) Explain in detail with phasor diagram of an alternator on load. (APRIL/2012)

Phasor Diagram of a Loaded Alternator

The phasor diagrams for various load power factor conditions are as follows. For drawing the phasor diagram consider all per phase values and remember following steps.

Steps to draw the phasor diagram:

1. Choose current as a reference phasor.

2. Now if load power factor is cos Φ it indicates that angle between V_{ph} and I_a is Φ as V_{ph} is the voltage available to the load. So show the phasor V_{ph} in such a way that angle between V_{ph} and I_a is Φ. For lagging 'Φ', I_a should lag V_{ph} and for leading 'Φ', I_a should lead V_{ph}. For unity power factor load Φ is zero, so V_{ph} and I_a are in phase.

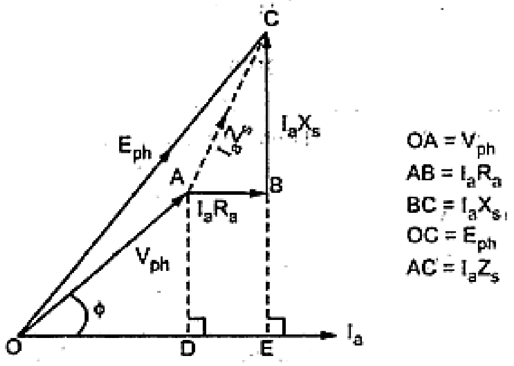
3. Now the drop I_a R_a is a resistive drop and hence will always be in phase with I_a. So phasor I_a R_a direction will be always same as I_a, i.e. parallel to I_a. But as it is to be added to V_{ph}, I_a R_a phasor must be drawn from the tip of the V_{ph} phasor drawn.

4. The drop I_a X_s is drop across purely inductive reactance. In pure inductance, current lags voltage by 90^0. So 'I_a X_s' phasor direction will be always such that I_a will lag I_a X_s phasor by 90^0. But this phasor is to be drawn from the tip of the I_a R_a phasor to complete phasor addition of V_{ph}, I_a R_a and I_a X_s.

5. Joining the starting point to the terminating point, we get the phasor E_{ph}. Whatever may be the load power factor, $I_a R_a$ is a resistive drop, will be in phase with I_a while $I_a X_s$ is purely inductive drop and hence will be perpendicular to I_a in such a way that I_a will lag $I_a X_s$ by 90^0. By using the above steps, the phasor diagrams for various load power factor conditions can be drawn.

Lagging Power Factor Load

The power factor of the load is cos Φ lagging so I_a lags V_{ph} by angle Φ. By using steps discussed above, phasor diagram can be drawn as shown in the Figure.



Phasor diagram for lagging p.f. load

To derive the relationship between E_{ph} and V_{ph}, the perpendiculars are drawn on the current phasor from points A and B. These intersect current phasor at points D and E respectively.

Now, $OD = V_{ph} \cos \Phi$

$AD = BE = V_{ph} \sin \Phi$

$DE = I_a R_a$

Consider ΔOCE, for which we can write,

$$(OC)^2 = (OE)^2 + (EC)^2$$

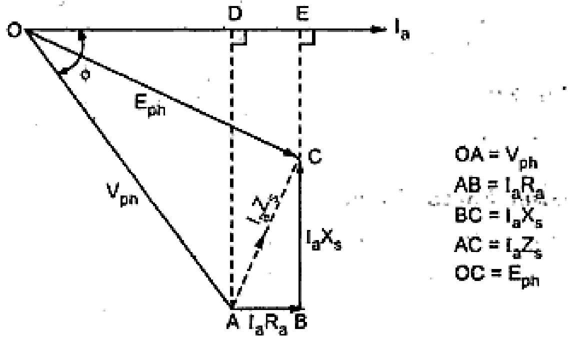
$$(E_{ph})^2 = (OD + DE)^2 + (EB + BC)^2$$

$$(E_{ph})^2 = (V_{ph} \cos \Phi + I_a R_a)^2 + (V_{ph} \sin \Phi + I_a X_s)^2$$

$$\boxed{E_{ph} = \sqrt{\left(V_{ph}\cos\Phi + I_aR_a\right)^2 + \left(V_{ph}\sin\Phi + I_aX_s\right)^2}}$$

Leading Power Factor Load

The power factor of the load is cos Φ leading. So I_a leads V_{ph} by an angle Φ. By using steps discussed, the phasor diagram can be drawn as shown in the Figure.



To derive the relationship between E_{ph} and V_{ph}, the perpendicular are drawn on the current phasor from points A and B. These intersect current phasor at points D and E respectively.

From ΔOCE, $OD = V_{ph} \cos \Phi$

$AD = BE = V_{ph} \sin \Phi$

$DE = I_a R_a$

Consider ΔOCE, for which we can write,

$$(OC)^2 = (OE)^2 + (EC)^2$$

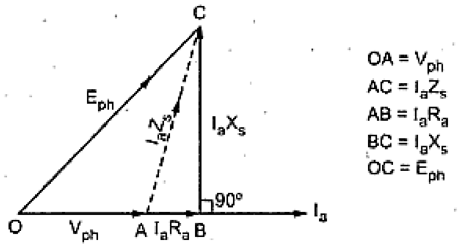
$$(E_{ph})^2 = (OD + DE)^2 + (BE - BC)^2$$

$$(E_{ph})^2 = (V_{ph} \cos \Phi + I_a R_a)^2 + (V_{ph} \sin \Phi - I_a X_s)^2$$

$$\boxed{E_{ph} = \sqrt{\left(V_{ph} cos\Phi + I_a R_a\right)^2 + \left(V_{ph} sin\Phi - I_a X_s\right)^2}}$$

Unity Power Factor Load

The power factor of the load is unity i.e. cos Φ = 1. So Φ = 0, which means V_{ph} is in phase with I_a. So phasor diagram can be drawn as shown in the



Consider ΔOBC, for which we can write,

$$(OC)^2 = (OB)^2 + (BC)^2$$

$$(E_{ph})^2 = (OA + AB)^2 + (BC)^2$$

$$(E_{ph})^2 = (V_{ph} + I_a R_a)^2 + (I_a X_s)^2$$

$$\boxed{E_{ph} = \sqrt{\left(V_{ph} + I_a R_a\right)^2 + \left(I_a X_s\right)^2}}$$

It is clear from the phasor diagram that V_{ph} is less than E_{ph} for lagging and unity p.f. conditions due to demagnetising and cross magnetizing effects of armature reaction. While V_{ph} is more than E_{ph} for leading p.f. condition due to the magnetizing effect of armature reaction.

Thus in general for any power factor condition,

$$\boxed{(E_{ph})^2 = (V_{ph} \cos\Phi + I_a R_a)^2 + (V_{ph} \sin\Phi \pm I_a X_s)^2}$$

+ sign for lagging p.f. loads

- sign for leading p.f. loads

V_{ph} = per phase rated terminal voltage

I_a = per phase full load armature current

6. Describe any two methods of determining the voltage regulation of three phase alternator (11) (NOV/2014)

VOLTAGE REGULATION OF AN ALTERNATOR

Under the load condition, the terminal voltage of alternator is less than the induced e.m.f. E_{ph}. So if load is disconnected, V_{ph} will change from V_{ph} to E_{ph}, if flux and speed is maintained constant. This is because when load is disconnected, I_a is zero hence there are no voltage drops and no armature flux to cause armature reaction. This change in the terminal voltage is significant in defining the voltage regulation.

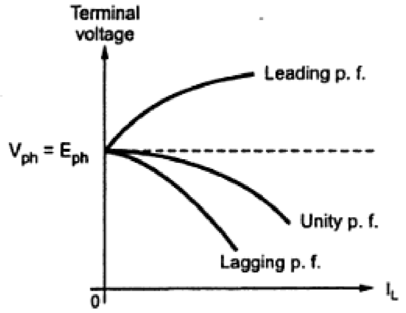
"The voltage regulation of an alternator is defined as the change in its terminal voltage when full load is removed, keeping field excitation and speed constant, divided by the rated terminal voltage."

So if V_{ph} = Rated terminal voltage

E_{ph} = No load induced e.m.f. The voltage regulation is defined as,

$$\boldsymbol{Regulation}\ \% = \frac{\boldsymbol{E\,ph - Vph}}{\boldsymbol{Vph}} \boldsymbol{X}\ \mathbf{100}$$

The value of the regulation not only depends on the load current but also on the power factor of the load. For lagging and unity p.f. conditions there is always drop in the terminal voltage hence regulation values are always positive. While for leading capacitive load conditions, the terminal voltage increases as load current increases. Hence regulation is negative in such cases. The relationship between load current and the terminal voltage is called load characteristics of an alternator. Such load characteristics for various load power factor conditions are shown in the below figure.



Load characteristics of an alternator

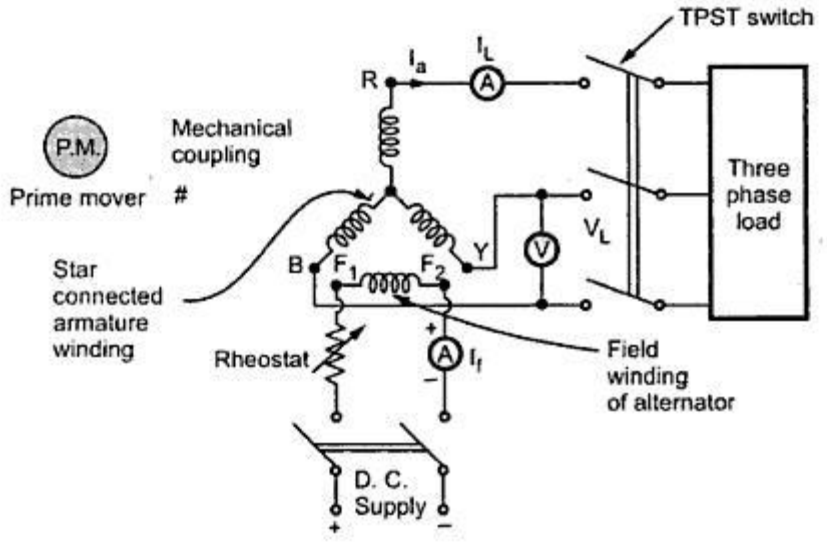
METHODS OF DETERMINING THE REGULATION

The regulation of an alternator can be determined by various methods. In case of small capacity alternators it can be determined by direct loading test while for large capacity alternators it can be determined by synchronous impedance method. Thus there following methods available to determine the voltage regulation of an alternator,

- ***Direct loading method***
- ***Synchronous impedance method or E.M.F. method***
- ***Ampere-turns method or M.M.F. method***
- ***Zero power factor method or potier triangle method***
- ***ASA modified form of M.M.F. method***
- ***Two reaction theory***

VOLTAGE REGULATION BY DIRECT LOADING

The below figure shows the circuit diagram for conducting the direct loading test on the three phase alternator. The star connected armature is to be connected to a three phase load with the help of triple pole single throw (TPST) switch. The field winding is excited by separate DC supply. To control the flux i.e. the current through field winding, a rheostat is inserted in series with the field winding. The prime mover is shown which is driving the alternator at its synchronous speed.



Circuit diagram for direct loading test on alternator

The alternator is first driven at its synchronous speed N_S by means of a prime mover. Now

$E_{ph} \;\alpha\; \Phi$ ..... (From e.m.f. equation)

By giving DC supply to the field winding, the field current is adjusted to adjust the flux so that rated voltage is available across the terminals. This can be observed on the voltmeter connected across the lines. The load is then connected by means of a TPST switch. The load is then increased so that ammeter reads rated value of current. This is full load condition of the alternator. Again adjust the voltage to its rated value by means of field excitation using a rheostat connected. The throw off the entire load by opening the TPST switch, without changing the speed and the field excitation. Observe the voltmeter reading. As load is thrown off, there is no armature current and associated drops. So the voltmeter reading in this situation indicates the value of internally induced e.m.f. called no load terminal voltage. Convert both the reading to phase values. The rated voltage on full load is Vph while reading when load is thrown off is E_{ph}. So by using the formula,

$$Regulation\ \% = \frac{E\,ph - Vph}{Vph} X\ 100$$

The full load regulation of the alternator can be determined. The value of the regulation obtained by this method is accurate as a particular load at required p.f. is actually connected to the alternator. But for high capacity alternators, that much full load cannot be simulated or directly connected to the alternator. Hence method is restricted only for small capacity alternators.

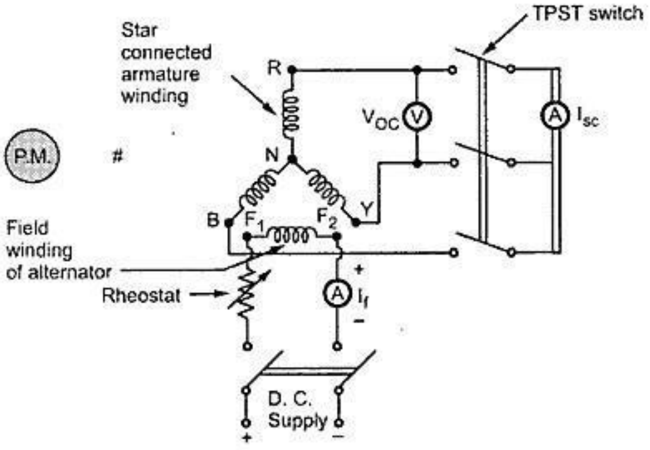
7. Explain the EMF method to determine the voltage regulation of an alternator. (APRIL/2013)

SYNCHRONOUS IMPEDANCE METHOD (OR) E.M.F. METHOD

The method is also called E.M.F. method of determining the regulation. The method requires following data to calculate the regulation.

- The armature resistance per phase (R_a).
- Open circuit characteristic which is the graph of open circuit voltage against the field current. This is possible by conducting open circuit test on the alternator.
- Short circuit characteristics which is the graph of short circuit current against field current. This is possible by conducting short circuit test on the alternator.

The circuit diagram is shown in the below figure.



Open Circuit Test

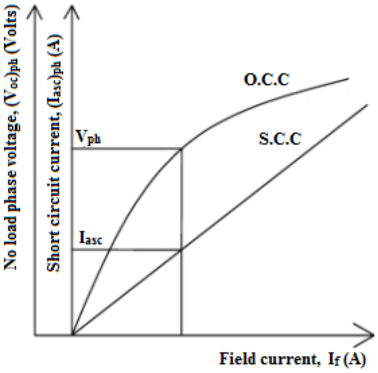
Procedure to conduct this test is as follows:

- The switch S across the load is kept open.
- Start the prime mover and adjust the speed to the synchronous speed of the alternator.
- Keeping rheostat in the field circuit (Alternator) maximum, switch on the DC supply.
- The T.P.S.T switch in the armature circuit is kept open.
- With the help of rheostat, field current is varied from its minimum value to the rated value. Due to this, flux increasing the induced e.m.f. Hence voltmeter reading, which is measuring line value of open circuit voltage, increases. For various values of field current, voltmeter readings are observed.

Short Circuit Test

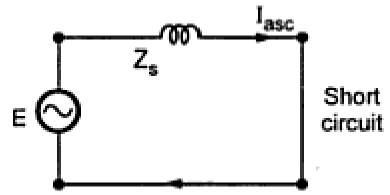
Procedure to conduct this test is as follows:

- The T.P.S.T switch is closed so the armature gets short circuited.
- Then the field excitation is gradually increased till full load current is obtained through armature winding.
- This can be observed on the ammeter connected in the armature circuit.
- The graph of short circuit armature current against field current is plotted from the observation table of short circuit test.
- This graph is called short circuit characteristics (S.C.C). This is also shown in the below figure.
- As S.C.C. is straight line graph, only one reading corresponding to full load armature current along with the origin is sufficient to draw the straight line.



Determination of Z_S from O.C.C and S.C.C

The synchronous impedance of the alternator changes as load condition changes. O.C.C. and S.C.C. can be used to determine Z_S for any load and load p.f. conditions. Consider a field current I_f. The O.C. voltage corresponding to this field current is E. When winding is short-circuited, the terminal voltage is zero. Hence, it may be assumed that the whole of this voltage E is being used to circulate the armature short- circuit current I_{asc} against the synchronous impedance Z_S. This can be shown in the equivalent circuit drawn in the below figure.

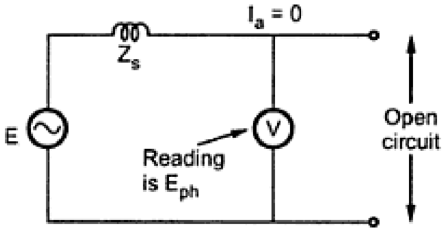


From the equivalent circuit we can write, $Z_S = E / I_{asc}$
Now value of I_{asc} is known, which can observe on the alternator. To determine Z_S it is necessary to determine value of E which is driving I_{asc} against Z_S.

Now internally induced e.m.f. is proportional to the flux i.e. field current I_f.

$E \propto \Phi \propto I_f$ ...... from e.m.f. equation

So if the terminals of the alternator are opened without disturbing I_f which was present at the time of short circuited condition, internally induced e.m.f. will remain same as E. But now current will be zero. Under this condition equivalent circuit will become as shown in the below figure.



It is clear now from the equivalent circuit that as $I_a = 0$ the voltmeter reading $(V_{oc})_{ph}$ will be equal to internally **induced** e.m.f. (E).

This is what we are interested in obtaining to calculate value of Z_S. So expression for Z_S can be modified as,

Thus in general,

$$Z_s = \left. \frac{\text{Phase e.m.f. on open circuit}}{\text{Phase current on short circuit}} \right|_{\text{For same excitation}}$$

So O.C.C. and S.C.C. can be effectively to calculate Z_S.

$$Z_s = \left. \frac{(V_{oc})_{ph}}{(I_{asc})_{ph}} \right|_{\text{for same } I_f}$$

The value of Z_S is different for different values of I_f as the graph of O.C.C. is non linear in nature. General steps to determine Z_S at any load condition are:

- Determine the value of $(I_{asc})_{ph}$ for corresponding load condition. This can be determined from known full load current of the alternator. For half load, it is half of the full load value and so on.
- S.C.C. gives relation between $(I_{asc})_{ph}$ and I_f. So for $(I_{asc})_{ph}$ required, determine the corresponding value of I_f from S.C.C.
- Now for this same value of I_f, extend the line on O.C.C. to get the value of $(V_{oc})_{ph}$. This is $(V_{oc})_{ph}$ for same I_f, required to drive the selected $(I_{asc})_{ph}$.
- The ratio of $(V_{oc})_{ph}$ and $(I_{asc})_{ph}$, for the same excitation gives the value of Z_S at any load conditions.

Regulation Calculations

From O.C.C. and S.C.C., Z_S can be determined for any load condition. The armature resistance per phase (R_a) can be measured by different methods. One of the methods is applying DC known voltage across the two terminals and measuring current. So value of R_a per phase is known.

Now,
$$Z_s = \sqrt{(R_a)^2 + (X_s)^2}$$
$$X_s = \sqrt{(Z_s)^2 - (R_a)^2}\ \Omega/\text{ph}$$

So synchronous reactance per phase can be determined.

No load induced e.m.f. per phase, E_{ph} can be determined by the mathematical expression derived earlier.

$$E_{ph} = \sqrt{(V_{ph} \cos\phi + I_a R_a)^2 + (V_{ph} \sin\phi \pm I_a X_s)^2}$$

Where, V_{ph} = Phase value of rated voltage
I_a = Phase value of current depending on the load condition
Cos Φ = p.f. of load

Positive sign for lagging power factor while negative sign for leading power factor, R_a and X_s values are known from the various tests performed.

The regulation then can be determined by using formula,

$$\textbf{Regulation}\,\% = \frac{E\,ph - Vph}{Vph} X\, 100$$

Advantages:

The main advantages of this method are the value of synchronous impedance Z_s for any load condition can be calculated. Hence regulation of the alternator at any load condition and load power factor can be determined. Actual load need not be connected to the alternator and hence method can be used for very high capacity alternators.

Disadvantages:

The main limitation of this method is that the method gives large values of synchronous reactance. This leads to high values of percentage regulation than the actual results. Hence this method is called ***pessimistic method.***

8. Explain the parallel operation of alternators (APRIL/2014)(or) With neat sketch, explain the parallel operation of an alternator.(NOV/2013)(APRIL/2012)

PARALLEL OPERATION AND SYNCHRONIZATION OF ALTERNATORS

INTRODUCTION

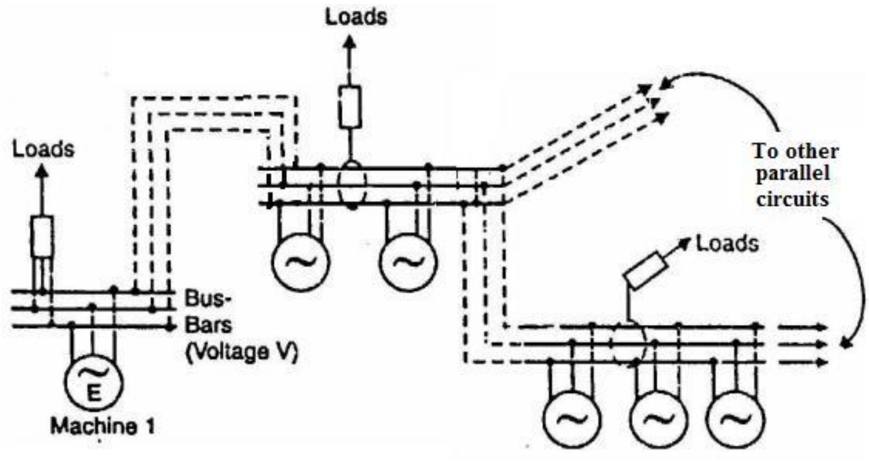
The process of switching of an alternator to another alternator or with a common bus bar without any interruption is called **synchronization.** Alternately it can also be defined as the process of connecting the two alternators in parallel without any interruption. The synchronous machine which is to be synchronized is normally called an incoming machine. If any alternators is connected to a bus bar which has many other alternators already connected, no matter what power it is supplying then alternator is said to be connected to infinite bus bar. An infinite bus bar is one of whose frequency and phase e.m.f. remains unaffected by changes in condition of any one machine connected to it. Thus they are nothing but constant frequency and constant voltage bus bars.

Parallel Operation of Alternators

It is rare to find a 3-phase alternator supplying its own load independently except under test conditions. In practice, a very large number of 3-phase alternators operate in parallel because the various power stations are interconnected through the national grid. Therefore, the output of any single alternator is small compared with the total interconnected capacity.

For example, the total capacity of the interconnected system may be over 40,000 MW while the capacity of the biggest single alternator may be 500 MW. For this reason, the performance of a single alternator is unlikely to affect appreciably the voltage and frequency of the whole system. An alternator connected to such a system is said to be connected to infinite busbars. The outstanding electrical characteristics of such busbars are that they are constant-voltage, constant frequency busbars.

The below figure shows a typical infinite bus system. Loads are tapped from the infinite bus at various load centres. The alternators may be connected to or disconnected from the infinite bus, depending on the power demand on the system. If an alternator is connected to infinite busbars, no matter what power is delivered by the incoming alternator, the voltage and frequency of the system remain the same. The operation of connecting an alternator to the infinite busbars is known as paralleling with the infinite busbars. It may be noted that before an alternator is connected to an infinite busbars, certain conditions must be satisfied.



Advantages

The following are the advantages of operating alternators in parallel:

- **Continuity of service.** The continuity of service is one of the important requirements of any electrical apparatus. If one alternator fails, the continuity of supply can be maintained through the other healthy units. This will ensure uninterrupted supply to the consumers.
- **Efficiency**. The load on the power system varies during the whole day; being minimum during die late night hours. Since alternators operate most efficiently when delivering full-load, units can be added or put off depending upon the load requirement. This permits the efficient operation of the power system.
- **Maintenance and repair**. It is often desirable to carry out routine maintenance and repair of one or more units. For this purpose, the desired unit/units can be shut down and the continuity of supply is maintained through the other units.
- **Load growth.** The load demand is increasing due to the increasing use of electrical energy. The load growth can be met by adding more units without disturbing the original installation.

CONDITIONS FOR PARALLELING ALTERNATOR WITH INFINITE BUS BARS

The proper method of connecting an alternator to the infinite busbars is called synchronizing. A stationary alternator must not be connected to live busbars. It is because the induced e.m.f. is zero at standstill and a short- circuit will result. In order to connect an alternator safely to the infinite busbars, the following conditions are met:

- The terminal voltage (r.m.s value) of the incoming alternator must be the same as busbars voltage.
- The frequency of the generated voltage of the incoming alternator must be equal to the busbars frequency.
- The phase of the incoming alternator voltage must be identical with the phase of the busbars voltage. In other words, the two voltages must be in phase with each other.
- The phase sequence of the voltage of the incoming alternator should be the same as that of the busbars.

The magnitude of the voltage of the incoming alternator can be adjusted by changing its field excitation. The frequency of the incoming alternator can be changed by adjusting the speed of the prime mover driving the alternator. Condition (i) is indicated by a voltmeter, conditions (ii) and (iii) are indicated by synchronizing lamps or a synchroscope. The condition (iv) is indicated by a phase sequence indicator.

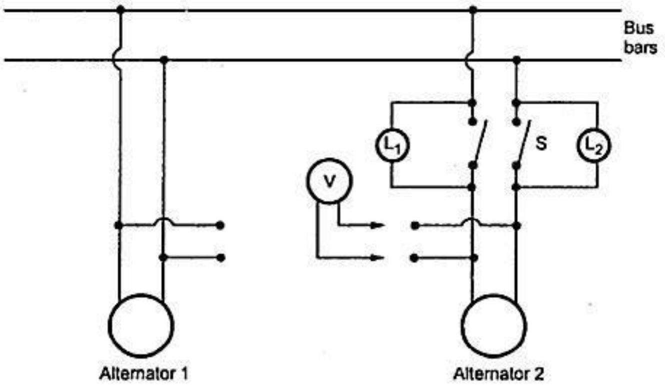
SYNCHRONIZATION OF SINGLE PHASE ALTERNATORS

In case of single phase alternators, synchronization is done generally by lamp methods. It can be done by two ways:

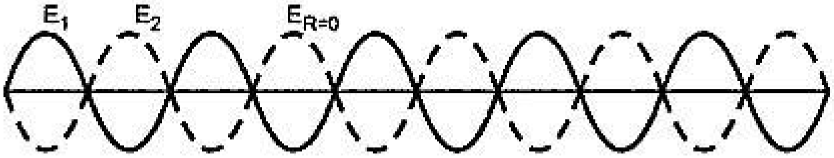
- Lamp dark method
- Lamps bright Method

1. Lamps Dark Method

In this method the lamps are arranged as shown in the below figure. The alternator to be synchronized (which is also called incoming alternator) consists of two lamps connected across the switch terminals of the same phase.

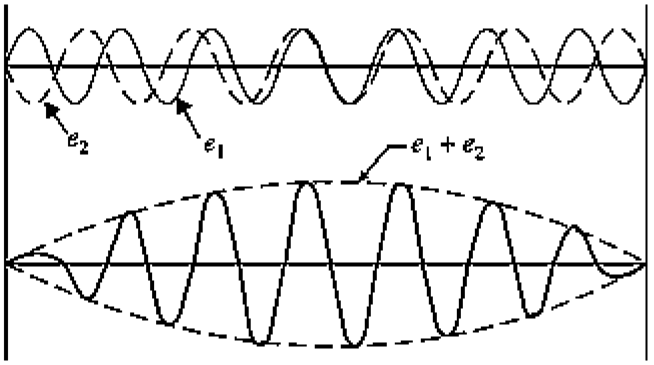


The voltage for the two alternators is measured with the help of a voltmeter. The lamps are connected in such a way that the polarity and the frequency for the two machines can be checked. No resultant voltage will appear across the switch terminals if the frequency of the two alternators is exactly same as their voltage is in exact phase opposition. Thus under this case lamps will not glow. This is represented in the below figure.



It can be seen that with unequal frequencies of the two alternators, the two lamps will become alternately bright and dark. The light beat will be produced whose number is equal to the difference in frequencies for the two machines.

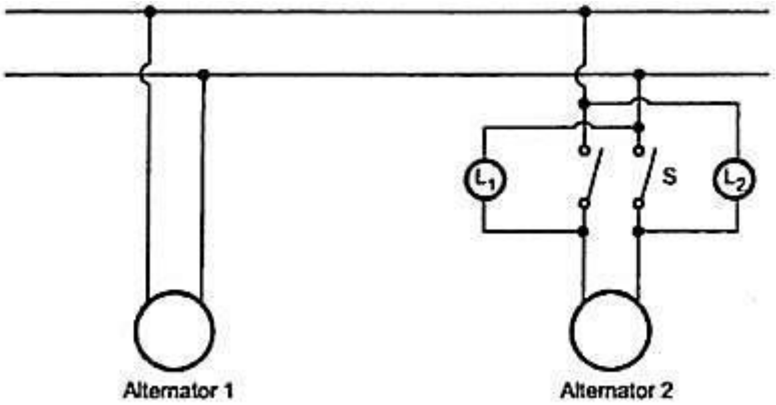
The resultant voltage appearing across the lamp will be difference of the two voltages at any instant resulting in a waveform shown in the below figure. Since number of cycle completed by two machines in any given time are not same the light beat is produced which is shown in the Figure



Sometimes the resultant voltage is maximum and some other times minimum. Hence, the current is alternating maximum and minimum. Due to this changing current through the lamps, a flicker will be produced, the frequency of the flicker being (f_2-f_1). Lamps will dark out and glow up alternatively. Darkness indicates that the two voltages E_1 and E_2 are in exact phase opposition relative to the local circuit and hence there is no resultant current through the lamps. Synchronizing is done at the middle of the dark period. The word middle is used as the lamp will not glow even though there is sufficient voltage across it. So it becomes difficult to know the correct instant of zero voltage. That is why, sometimes, it is known as ‘lamps dark’ synchronizing

2. Lamps Bright Method

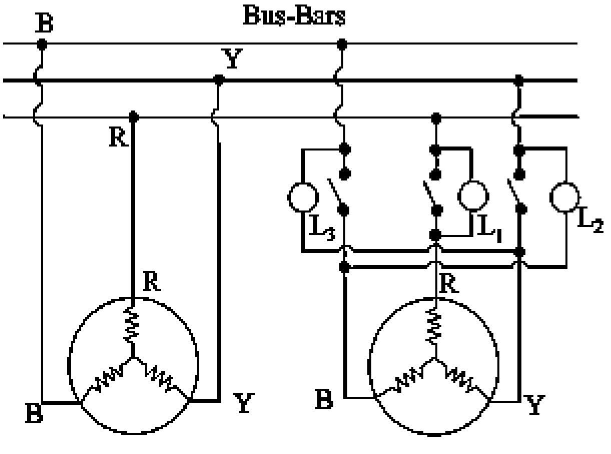
Since it is very difficult to judge the correct instant of zero voltage in Lamps dark method, this method is introduced which is shown in the below figure.



The lamps remain maximum bright when there is no difference in voltages for the two machines. This is more sharp and accurate method of synchronization because the lamps are much more sensitive to changes in voltage at their maximum brightness than when they are dark.

SYNCHRONIZATION OF THREE PHASE ALTERNATORS

The conditions to be satisfied for synchronization of three phase alternators are same as that for single phase alternators. But instead of saying that voltages must act in phase opposition, the phase sequence must be same i.e. phase must be connected in proper order of R, Y, B. Typical setup for synchronization of alternators is shown in the below figure.



Setup for Synchronization of Alternators

In synchronizing three phase alternators, three lamps are connected as shown in the Fig.2, so that it can be used to indicate whether the incoming machine is running slow or fast. With symmetrical connection of lamps, they would dark out or glow up simultaneously provided that phase sequence is same for incoming machine and bus bar.

Consider the two alternators A and B to be synchronized. The alternator A is already running at synchronous speed and its excitation is so adjusted that it builds up the rated voltage. The alternator B is to be connected to bus bar i.e. it is to be synchronized with alternator A. The process or synchronization can be explained as below:

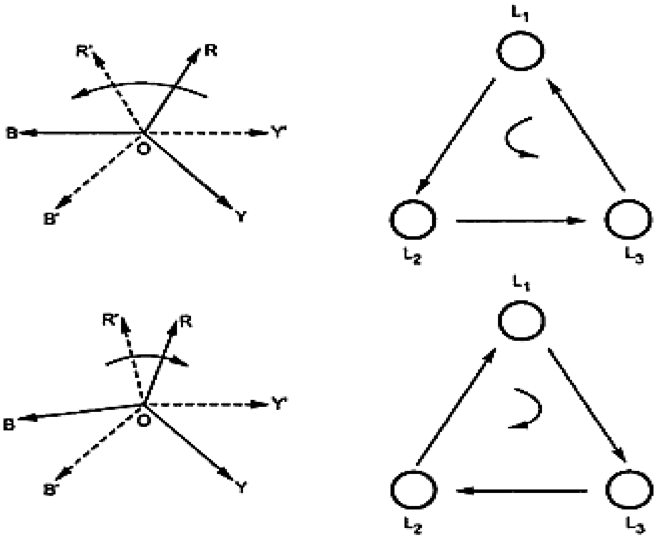
Step 1: Start the prime mover of machine B and adjust its speed to a synchronous speed.

Step 2: By adjusting the rheostat, the excitation to the field is adjusted so that induced e.m.f. of B is equal to the induced e.m.f. of A. This can be verified by voltmeter.

Step 3: To satisfy remaining conditions, the three lamps pairs are used which are L_1, L_2 and L_3 as shown in the above figure. These are connected in such a way that pair L_1 is straight connected while the pairs L_2 and L_3 are cross connected. The phasor $E_{RR'}$, joining the tips R and R' is voltage across lamp pair L_1. Similarly E_{YB}, and E_{BY}, are voltages across lamps L_2 and L_3 respectively.

If there is difference between the two frequencies due to difference in speeds of the twp alternators, the lamps will become dark and bright in a sequence. This sequence tells whether incoming alternator frequency is less or greater than machine A.

The sequence L1, L2, L3 tells that machine B is faster as the voltage star R'Y'B' will appear to rotate anticlockwise with respect to bus bar voltage RYB at a speed corresponding to difference between their frequencies shown in the below figure. The sequence L3, L2, L1 tells that the machine B is slower because voltage star R'Y'B' will appear to rotate clockwise with respect to bus bar voltage RYB. The prime mover speed can be adjusted accordingly to match the frequencies.



The synchronization is done at the moment when lamp L1 is in the middle of dark period. If the lamps pair becoming dark and bright simultaneously, it indicates incorrect phase sequence which can be correct by interchanging any two leads either of the incoming machine or of bus bars. In this method when lamp L1 is dark the other two lamp pairs L2 and L3 and equally bright. So this method of synchronization is called **"Lamps bright and dark" method.**

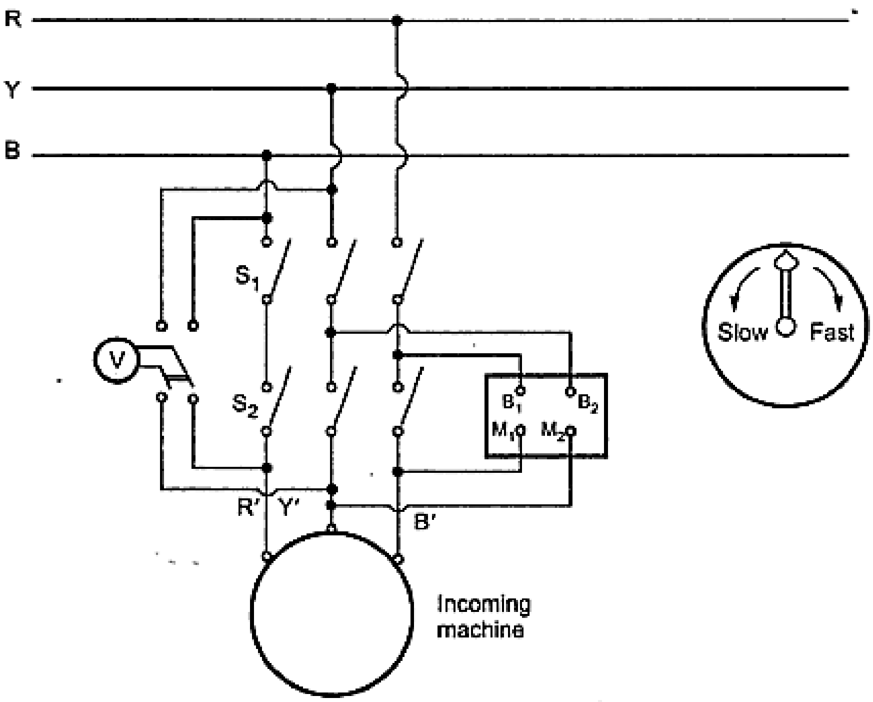
Synchronization by Synchroscope

It can be seen that the previous method is not accurate since it requires correct sense of judgement of the operator. Hence to avoid the personal judgement, the machines are synchronized by accurate device known as synchroscope.

It consists of a rotating pointer which indicates the exact moment of closing the synchronizing switch. If the pointer rotates in anticlockwise direction, it indicates that incoming machine is running slow whereas clockwise rotation of pointer indicates that incoming machine is running faster. The rotation of pointer is proportional to the difference in the two frequencies. The pointer should rotate at a very low speed in the direction of arrow marked fast as shown in the below figure.

When the rotating pointer reaches the vertical position at slow speed, the switch must be closed. The pointer will oscillate about some mean position instead of rotating if difference in frequencies is large. In such cases the speed of incoming machine is adjusted properly.

The connections for synchroscope are shown in Figure Any two bus bars lines are connected to its terminals while its other terminals are connected to corresponding lines of incoming machine. The phase sequence can be checked with the help of phase sequence indicator. The voltmeter is used to check the equality of voltage of bus bars and incoming machine. The synchronization procedure is already explained before.



The use of lamps and synchroscope together is a best method of synchronization.

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4. ELECTRONCS

Op.Amp. – Characteristics – Inverting amplifier - Non-inverting amplifier -differentiation integration I/V converter - V/I converter - Instrumentation amplifier – adder – subtractor – First order low pass filter and High pass filter using op. Amp

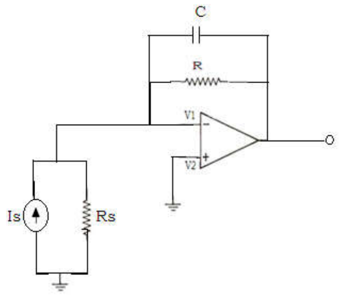
Part –A (2 Marks)

1. **List out the ideal characteristics of OPAMP.**(APRIL/2013)(APRIL/2014)(NOV/2014)
    - An ideal op amp draws no current in both the input terminals. Therefore its impedance is infinite. Any source can drive it and there is no loading on the driver stage.
    - The gain of an ideal op-amp is infinite, hence the differential input V_d= (V_1-V_2) is essentially zero for the infinite output voltage.
    - The output voltage V_0 is independent of the current drawn from the output terminals. Thus its output impedance is zero and hence output can drive an infinite number of other circuits.
2. **Mention some of the applications of OPAMP** (NOV/2014)
    - Instrumentation amplifier
    - V to I converter
    - I to V converter
    - comparator
3. **What do you mean by inverting amplifier?**(APRIL/2012/2014)

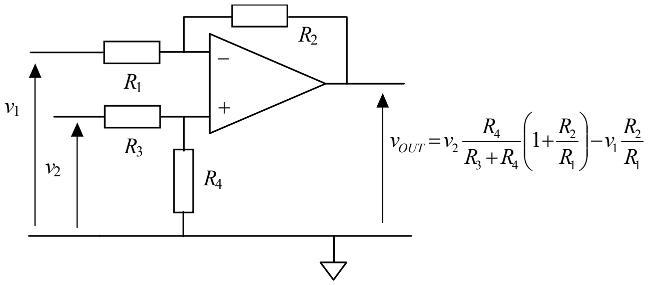
    The output of such an amplifier is inverted as compared to the input signal. The inverted output signal means having a phase shift of 180° as compared to the input signal. So, am amplifier which provides a phase shift of 180° between input and output is called inverting amplifier.
4. **What is an operational amplifier** (NOV/2013)

    The operational amplifier most commonly referred as 'op-amp' was introduced in 1940s. The operational amplifiers performs addition, subtraction, multiplication etc. due to its use in performing mathematical operations, it has been given as operational amplifier.

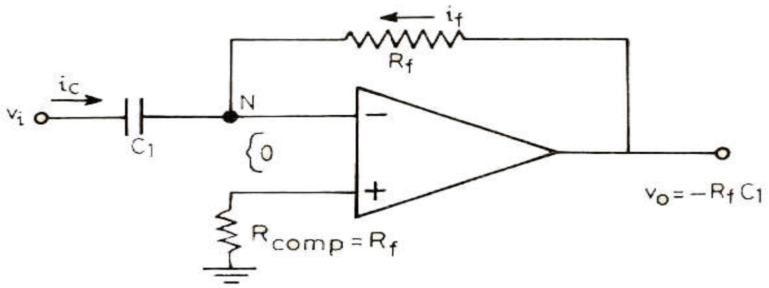
5. **Draw the circuit diagram of I to V converter** (NOV/2013)



6. **Draw the circuit diagram of subractor.** (APRIL/2013)


R_2
R_1
v_1
R_3
v_2
R_4
$v_{OUT} = v_2 \frac{R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right) - v_1 \frac{R_2}{R_1}$

7. **Draw the circuit diagram of op-amp differentiator**. (NOV/2012)



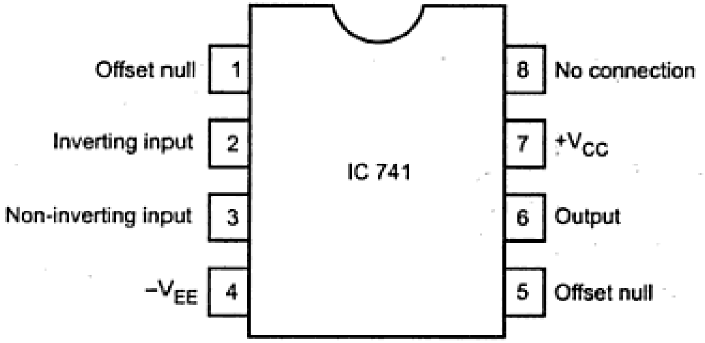
8. **What is meant by filter?** (NOV/2012)

A filter is a circuit that is designed to pass a specific band of frequencies while attenuating all the signals outside that band. It is a frequency selective circuit.

9. **Mention some applications of an instrumentation amplifier**. (APRIL/2012)

- Temperature controller
- Temperature indicator
- Light intensity meter
- Analog weight scale

10. **Draw the pin configuration of IC741**.

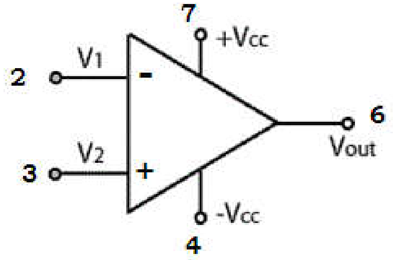


Part-B (11 Marks)

1. Explain about the basic of IC 741 by using its ideal and practical characteristics.

OPERATIONAL AMPLIFIER: (Op-Amp)

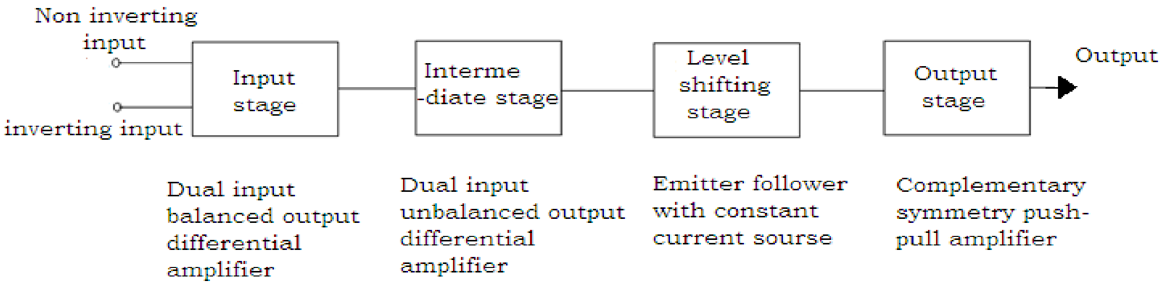
An operational amplifier or OP-AMP is a DC-coupled voltage amplifier with a very high voltage gain. Op-amp is basically a multistage amplifier in which a number of amplifier stages are interconnected to each other in a very complicated manner. Its internal circuit consists of many transistors, FETs and resistors. All this occupies a very little space. So, it is packed in a small package and is available in the Integrated Circuit (IC) form. The term Op-Amp is used to denote an amplifier which can be configured to perform various operations like amplification, subtraction, differentiation, addition, integration etc.



OP-AMP

An op-amp has two input terminals and one output terminal. The op-amp also has two voltage supply terminal. It has a differential input and a single ended output. The terminal marked as negative (-) is called as an inverting terminal and the terminal marked as positive (+) is called as a non-inverting terminal of the operational amplifier. If we connect an input signal at the inverting terminal (-) of the op-amp than the amplified output signal is π radians (180°) out of phase with respect to the applied input signal. If an input is connected to the non-inverting terminal (+) than the output signal obtained will be in phase i.e. it will have no phase shift with respect to the input signal.

BLOCK DIAGRAM OF OP-AMP


Non inverting input
inverting input
Input stage
Interme -diate stage
Level shifting stage
Output stage
Output
Dual input balanced output differential amplifier
Dual input unbalanced output differential amplifier
Emitter follower with constant current sourse
Complementary symmetry push-pull amplifier

Block Diagram of an OP AMP

This contains four stages,

INPUT STAGE

The input stage is a Dual input balanced output differential amplifier. The two amplifiers are applied at inverting or non inverting terminals. This stage provides most of voltage gain of the op-amp and decides input resistance value R_1.

INTERMEDIATE STAGE

This is usually another differential amplifier. It is driven by output of the input stage. This stage is dual input unbalance output differential amp. This stage provides additional voltage gain to the input signals.

LEVEL SHIFTING STAGE

This is third stage in the block diagram of op-amp. Due to direct coupling between first two stages the input of level shifting stage is an amplifying system with non-zero DC level. Level shifting stage is used to bring this DC level to a zero volt with respect to ground.

OUTPUT STAGE

This is normally complementary output stage. It increases magnitude of voltage and rises the current supplying capacity of the op-amp. It also provides low output resistance. The output stage is a push pull of two transistors

Advantages of Op-Amp

- Good thermal stability
- Low offset voltage
- Low offset current
- High reliability

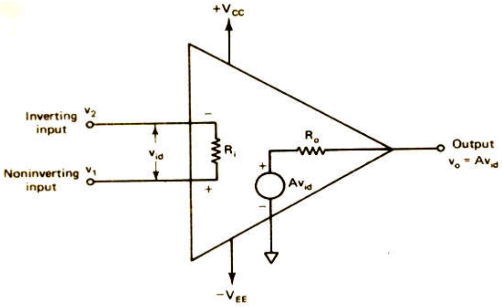
Disadvantages of Op-Amp

- It is difficult to realize the large values of resistance and capacitance.
- No methods to fabricate transformer using linear IC's.

Applications of Op-Amp

The integrated op-amp's offers all the advantages of IC's such as high reliability, small size, cheap, less power consumption. They are used in variety of applications such as Inverting & Non-inverting amplifiers, Unity gain buffer, Summing amplifier, Differentiator, Integrator, Adder, Instrumentation amplifier, Wien bridge oscillator, Filters etc.

Equivalent Circuit of Op-Amp:



Equivalent Circuit

IDEAL OP-AMP CHARACTERISTICS

- Infinite voltage gain (So that maximum output is obtained)
- Infinite input resistance (Due to this almost any source can drive it)
- Zero output resistance (So that there is no change in output due to change in load current)
- Infinite bandwidth
- Zero noise
- Zero power supply rejection ratio (PSSR=0)
- Infinite common mode rejection ratio (CMMR=∞)

CHARACTERISTICS OF OP- AMP:

Characteristics of op-amp is classified into two types, They are

- AC characteristics
- Dc characteristics

AC Characteristics:

AC characteristics can be further classified into two forms

- Slew rate

SLEW RATE:

It is the maximum rate of change of output voltage passed by a stepped input voltage. It is denoted by SR. The value is 0.5v/us.

FREQUENCY RESPONSE

Closed Loop Gain:

In closed loop gain there will be some feedback. Feedback is nothing but the elements like capacitors or resistors is connected across the input and output terminals.

Open Loop Gain:

In open loop gain, there will not be any feedback. For 741 IC in open loop gain the value is infinity.

DC Characteristics:

DC characteristics can be further classified into many forms.

- Input bias current
- Input offset current
- Input offset voltage
- Input resistance
- Input capacitance
- Output offset voltage
- Thermal drift

Thermal drift is further classified into two types

- Input offset current drift
- Input offset voltage drift

- **INPUT BIAS CURRENT**:

  The average of the currents entering in to the (-)input and(+)input terminals of an op-amp is called as an input bias current. Its value is 500nA for IC741.
- **INPUT OFFSET CURRENT**:

  The algebraic difference between the currents in the (-) input and (+) input is referred to as input offset current. It is 200nA for IC741.
- **INPUT OFFSET VOLTAGE**:

  It is the voltage difference that must be applied between the input terminals of an op-amp. Since the voltage could be positive or negative. For IC741, the maximum value is 6mv.
- **INPUT RESISTANCE**:

  This is the differential input resistance of input terminals with the other terminal connected to the ground. For the IC741, the input resistance is 2Mohms.
- **INPUT CAPACITANCE**:

  It is the equivalent capacitance that can be measured at either of the input terminal with the other terminal connected to the ground. A typical value of Ci is 1.4pF.
- **INPUT VOLTAGE:**

  This is the common mode voltage that can be applied to both input terminals without disturbing the performance of an op-amp. For the 741c, their range is (+ or -)13V.
- **COMMON MODE REJECTION RATIO☹CMRR)**

  It is the ability of op-amp to reject the signal common to both the inputs. Generally, it is high. For 741c, the value is 90db.
- **SUPPLY VOLTAGE REJECTION RATIO:**

  The change in an op amp's input offset voltage due to variations in supply voltage is called supply voltage rejection ratio. For 741c, the value is 150uV\V. It is also called as power supply rejection ratio.
- **OUTPUT OFFSET VOLTAGE**:

  It is the voltage presented at the output terminal when both the input terminals are grounded. For 741 IC, the value is (+ or -) 15mV.

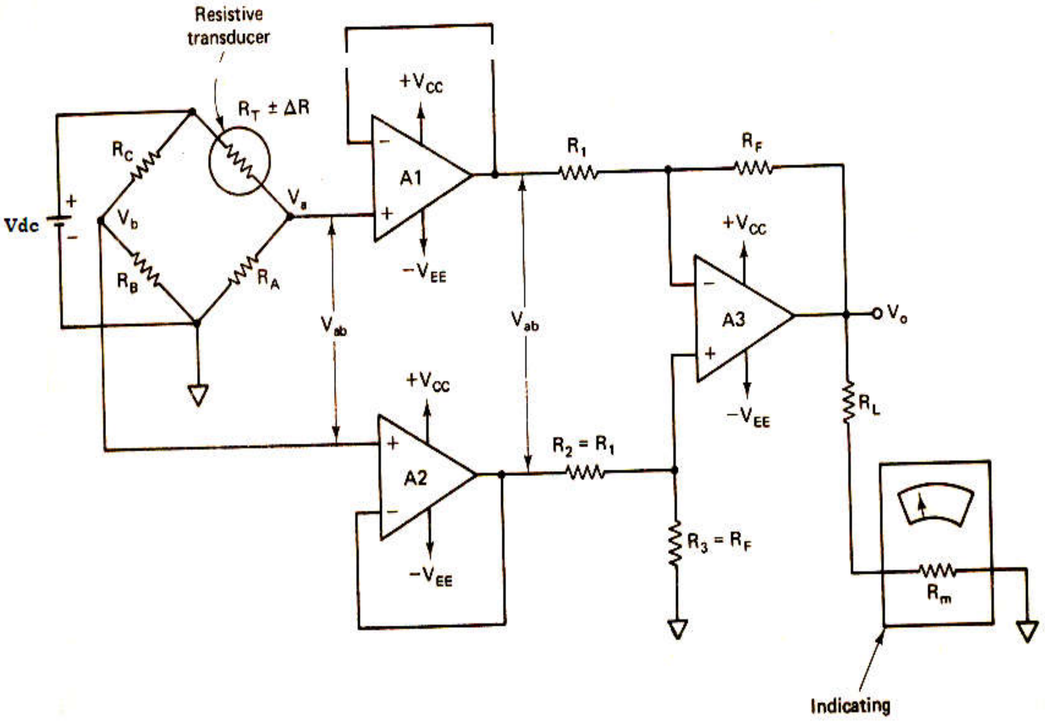
- **INPUT OFFSET CURRENT DRIFT**:
  It is the rate of change of input offset current with respect to the temperature of balanced op amp. The value is 0.2nA/degree celcius.
- **INPUT OFFSET VOLTAGE DRIFT**:
  The rate of change of input offset voltage with respect to the temperature of balanced op amp. Its value is 0.15mV/degree celcius.

- **INPUT COMMON MODE RANGE:**
  It is the maximum range of signal that can be applied as a common mode. For 741c, the value is (+ or -)13v.
- **INPUT DIFFERENTIAL RANGE**:
  It is the maximum differential signal that can be applied to the input terminals of the op amp without affecting the normal operations.
- **COMMON MODE GAIN**:
  It is the ratio of common mode output voltage to common mode input voltage. The value is less than 1v. It is denoted by Avcm.
- **DIFFERENTIAL MODE GAIN:**
  It is the ratio of differential mode output voltage to the differential mode input voltage. It is denoted as Avdm.
- **OUTPUT RESISTANCE**:
  It is the resistance measured at the output terminal of op amp with respect to ground for 741c, the value is 75 ohms.
- **POWER CONSUMPTION**:
  It is the quiescent power consumed by the op amp for its operation. For 741c, the value is 85mv.
- **OUTPUT SHORT CIRCUIT CURRENT**:
  This is the current that may flow if an op amp gets shorted accidentally. For 741c, the value is 85mv.
- **FULL POWER BAND WIDTH:**
  It is the maximum frequency up to which the output voltage range can obtain without distortion

2. Explain the working of an instrumentation amplifier with a circuit. Give its characteristics and application (11) (NOV2012/APRIL/NOV/2014)

   In many industrial and consumer applications the measurement and control of physical conditions are very important.(foreg) measurement of temperature & humidity inside a dairy or a meat plant permit the operators make necessary adjustments to maintain product quality. Similarly precise temperature control of plastic furnace is needed to produce a particular type of plastic.Generally, a transducer is used at the measuring site to obtain the required information easily & safely. The transducer is a device that converts one form of energy into another.

   A resistive transducer whose resistance changes as a function of some physical energy is connected in one arm of bridge with a small circle around it & is denoted by (R ± ΔR), where R_T is the resistance of transducer and ΔR the change in resistance of RT. The bridge in the circuit is dc exited but could be ac exited as well. For the balanced bridge at some reference condition,



$$V_b = V_a$$

$$\frac{R_B(V_{dc})}{R_B + R_c} = \frac{R_A(V_{dc})}{R_A + R_T}$$

$$\frac{R_c}{R_B} = \frac{R_T}{R_A}$$

Generally resistors R_A, R_B, R_C are selected so that they are equal in value to the transducer resistance R_T at some reference condition the reference condition is the specific value of the physical quantity under measurement at which the bridge is balanced this value is normally established by the designer and depends on the transducer's characteristics, the type of physical quantity to be measured, and the desired application.The bridge is balanced initially at a desired reference condition. However, as the physical quantity to be measured changes, the resistance of the transducer also changes, which causes the bridge to unbalance ($Va \neq Vb$). The output voltage of the bridge can be expressed as a function of the change in resistance of the transducer.

Let the change in resistance of the transducer be Δ_R . Since R_b&R_c Are fixed resistors, the voltage V_b is constant. However, the voltage V_a varies as a function of the change in transducer resistance. Therefore, according to the voltage divider rule,

$$V_a = \frac{R_A(V_{dc})}{R_A + (R_T + \Delta\mathrm{R})}$$

$$V_a = \frac{R_{BA}(V_{dc})}{(R_B + R_c)}$$

Consequently, the voltage V_{ab} across the output terminals of the bridge is,

$V_{ab} = V_a - V_b$

$$V_{ab} = \frac{R_A V_{dc}}{R_A + R_T + \Delta R} - \frac{R_B V_{dc}}{R_B + R_c}$$

However, if $R_A = R_B = R_C = R_T = R$, then

$$V_{ab} = \frac{\Delta R(V_{dc})}{2(2R + \Delta R)}$$

the (-)ve sign indicates that $V_a < V_b$(since RT increases)

The basic gain differential amplifier is $(-R_F/R_1)$

$$V_0 = V_{ab} - \frac{R_f}{R_1} = \frac{\Delta R(V_{dc})}{2(2R+\Delta R)}\frac{R_f}{R_1}$$

Generally, R is very small. Therefore we can approximate (2R + R) = 2R.

$$V_0 = \frac{R_f}{R_1}\frac{\Delta R}{4R}V_{dc}$$

This equation indicates that V is directly proportional to the change in resistance R of the transducer since the change in resistance is caused by a change in physical energy, a meter connected at the output can be calibrated in terms of the units of that physical energy.

Features of Instrumentation Amplifier

- High gain
- High CMRR
- Low Power consumption
- High slew rate

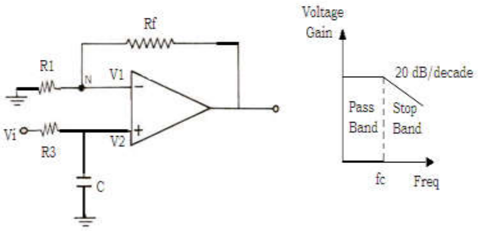
Applications of Instrumentation Amplifier

- Temperature indicator
- Light-intensity meter
- Thermal conductivity meter
- Analog weight scale

3. Draw the circuit of a first order and second order butter worth active low pass filter and derive the transfer function (11) (APRIL/2013)(NOV/2014)

(i)Low pass filter

The first order low pass Butterworth filter is realized by RC circuit used along with an op-amp, used in the non- inverting configuration. This is also called one pole low pass Butterworth filter. The resistances R_f and R_1 decide the gain of the filter in the pass band.



First Order Low Pass Butterworth Filter

Analysis of the filter circuit

The impedance of the capacitor C is $-jX_c$ where X_c is the capacitive reactance given by

$$X_c = 1/(2\pi fC).$$

By potential divider rule, the voltage at the non-inverting input terminal 2 which is the voltage across the capacitor C is given by

RC filter is connecting non inverting input

$$V_2 = \left[\frac{{}^{1}/_{j\omega C}}{R_3 + {}^{1}/_{j\omega C}}\right]V_i$$

$$\omega = 2\pi f$$

$$V_2 = \left[\frac{1}{1 + j\omega R_3 C}\right] V_i$$

General non inverting output

$$V_0 = \left[1 + \frac{R_f}{R}\right] V_{in}$$

We can write,

$$V_0 = \left[1 + \frac{R_f}{R}\right]\left[\frac{1}{1 + j\omega R_3 C}\right] V_i$$

$$\frac{V_0}{V_i} = \left[1 + \frac{R_f}{R}\right]\left[\frac{1}{1 + j\omega R_3 C}\right]$$

$$\frac{V_0}{V_i} = \left[1 + \frac{R_f}{R}\right]\left[\frac{1}{1 + j2\pi f R_3 C}\right]$$

$$\frac{V_0}{V_i} = \frac{A_f}{1 + j\left({}^{f}/_{f_C}\right)}$$

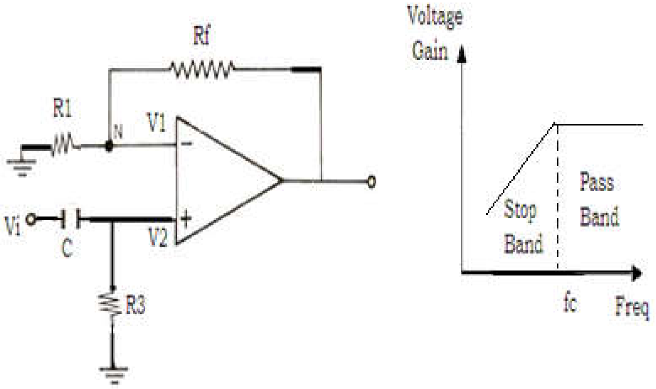
$$A_f = 1 + \frac{R_f}{R}$$

f- *Frequency of input signal*

f_C-*Cutoff frequency of filter*

$$f_C = \frac{1}{2\pi R_3 C}$$

(i)**High Pass Filter**



High Pass Filter

$$V_2 = \frac{R_3}{R_3 + \frac{1}{j\omega C}}$$

$$V_2 = \frac{j\omega R_3 C}{1 + j\omega R_3 C} V_i$$

For non inverting output

$$V_0 = \left[1 + \frac{R_2}{R_1}\right] V_2$$

$$\frac{V_0}{V_i} = \left[1 + \frac{R_2}{R_1}\right]\left[\frac{j\omega R_3 C}{1 + j\omega R_3 C}\right]$$

$$\frac{V_0}{V_i} = \left[1 + \frac{R_2}{R_1}\right]\left[\frac{j2\pi f R_3 C}{1 + j2\pi f R_3 C}\right]$$

$$\frac{V_0}{V_i} = A_f\left[\frac{j\frac{f}{f_C}}{1 + j\frac{f}{f_C}}\right]$$

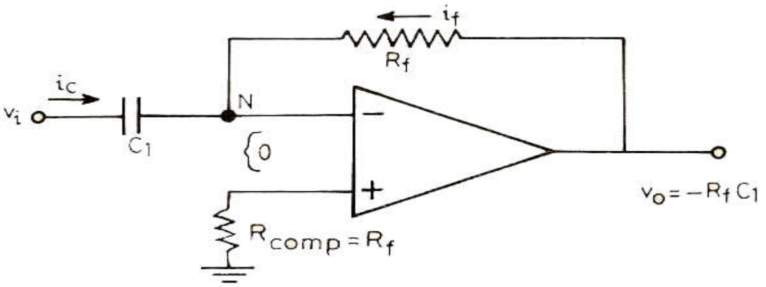
Where $A_f = \frac{R_2}{R_1} + 1$

$$fc = \frac{1}{2\pi R_3 C}$$

4. Explain the analysis of differentiator. (NOV/2013)(APRIL/2014)

The circuit which produces the differentiation of the input voltage at its output is called differentiator. The differentiator circuit which does not use any active device is called passive differentiator. While the differentiator using an active device like op-amp is called an active differentiator.The circuit performs the mathematical operation of differentiation. i.e. the output wave form is the derivative of the input waveform. The differentiator provides a constant output above a cut-off frequency and passes no signal below this frequency. So the differentiator is also called as high pass filter (HPF).The non-inverting terminal (3) is grounded. Therefore node ‘a’ voltage is zero.

i.e. Va = 0



(i.e.) V_o ∞dVi

At node ‘a’,

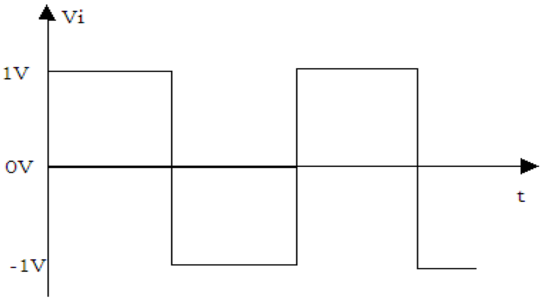
$$C_f \frac{dV_i}{dt} + \frac{V_0}{R_f} = 0$$

- ✓ The node ‘a’ is virtually grounded. Therefore $V_n = V_a = 0$

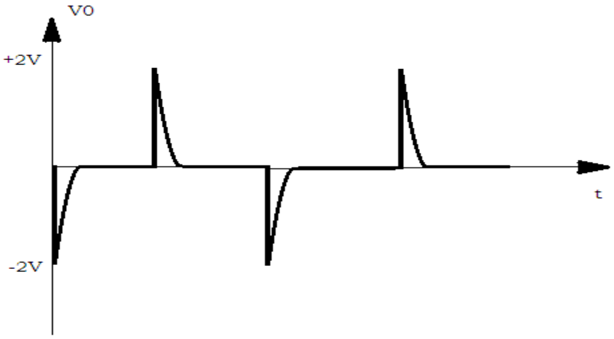
$$\frac{V_0}{R_f} = -C_1 \frac{dV_i}{dt}$$

- ✓ Here the –ve sign is introduced because the input is given to the inverting terminal

The equation shows that the output is C_1R_f times the differentiation of the input and product C_1R_f is called time constant of the differentiator.



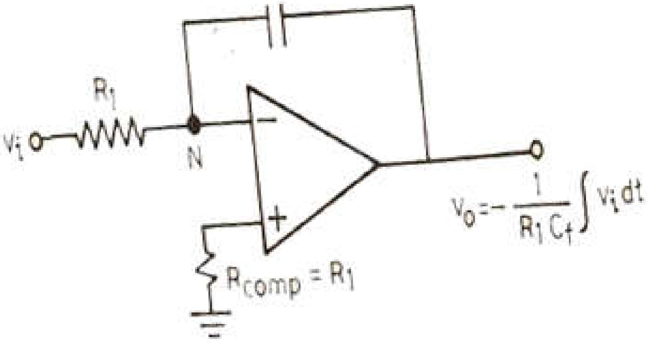
Input to Differentiator



Output of Differentiator

5. Draw and explain the operation of integrator circuits. (NOV/2013)

In an integrator circuit, the output voltage is the integration of the input voltage. The integrator circuit can be obtained without using active devices like op-amp, transistors etc. in such a case an integrator is called passive integrator. While an integrator using an active device like an op-amp is called active integrator. The integrator provides a constant output below a cut-off frequency and passes no signal above this frequency. So the integrator is also called as low pass filter (LPF). If we inter change the resistor and the capacitor of the differentiator we get the circuit of an integrator.



The non- inverting terminal is grounded. The node N is also at ground potential from the concept of virtual ground.$V_N = 0$, as input current of op-amp is zero, the entire current I flowing through R_1, also flows through C_f (i.e) Vo ∞ Vi

At node ‘a’

$$\frac{V_i}{R_1} + C_f\frac{dV_0}{dt} = 0$$

$$C_f\frac{dV_0}{dt} = -\frac{V_i}{R_1}$$

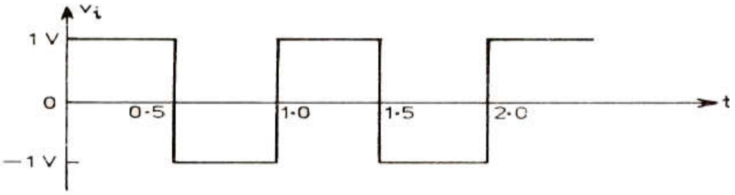
$$\frac{dV_0}{dt} = -\frac{V_i}{R_1C_f}$$

$$dV_0 = -\frac{V_i dt}{R_1C_f}$$

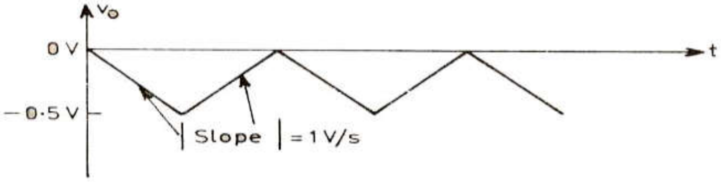
Integrating on both sides

$$\int dV_0 = -\frac{V_i * dt}{R_1C_f}$$

$$\int dV_0(t) = \left(\frac{1}{C_fR_1}\right)\int V_i(t)$$



Input to Integrator



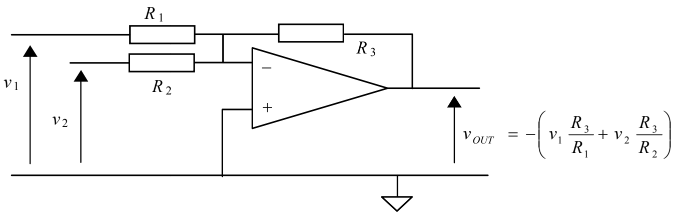
Output of Integrator

6. With neat circuit diagram explain the operation of adder and subtractor. (APRIL2012) (NOV/2012) (NOV/2013)

A circuit whose output is the sum of all the inputs given is called summer or summing amplifier. There are two types of summer (i) inverting summer & (ii) non-inverting summer.

(i) Inverting Summer

A summer amplifier with two input voltages V1 and V2, two input resistors R1 and R2, feedback resistor Rf is shown in the fig. below


R_1
R_2
R_3
v_1
v_2
−
+
$v_{OUT} = -\left(v_1\frac{R_3}{R_1} + v_2\frac{R_3}{R_2}\right)$

Inverting Summer

The voltage at the node ‘a’ is zero as the non- inverting input terminal is virtually grounded.

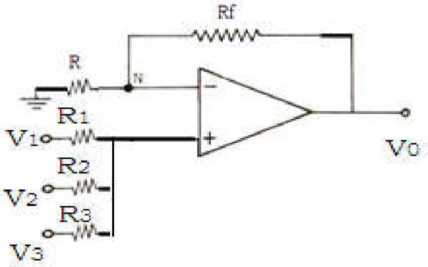
The nodal equation by KCL at node ‘a’ is

$$\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_0}{R_3}=0$$

$$V_0={}^{R_f}\!/_{R_1}\,(V_1+V_2)$$

$$V_0\infty(V_1+V_2)$$

(ii) Non Inverting Summer



Non Inverting Summing amplifier

For non inverting,

$$V_0=\left[1+\frac{R_f}{R}\right]V_{in}$$

$$V_{in}=\frac{{}^{V_1}\!/_{R_1}+{}^{V_2}\!/_{R_2}+{}^{V_3}\!/_{R_3}}{{}^{1}\!/_{R_1}+{}^{1}\!/_{R_2}+{}^{1}\!/_{R_3}}$$

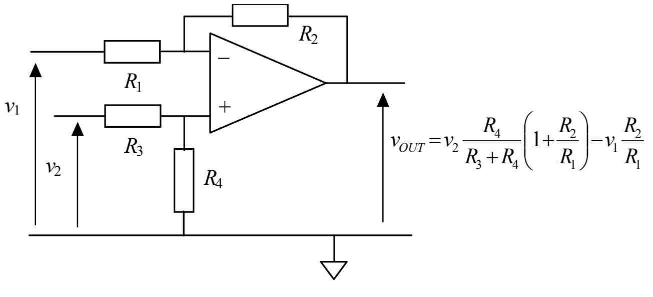
$$V_0=\left[1+\frac{R_f}{R}\right]\left[\frac{{}^{V_1}\!/_{R_1}+{}^{V_2}\!/_{R_2}+{}^{V_3}\!/_{R_3}}{{}^{1}\!/_{R_1}+{}^{1}\!/_{R_2}+{}^{1}\!/_{R_3}}\right]$$

If $R_1=R_2$=$R_3=R$

$$V_0=\left[1+\frac{R_f}{R}\right]\left[\frac{V_1+V_2+V_3}{3}\right]$$

(iii)DIFFERENTIAL AMPLIFIER (or) SUBTRACTOR

A circuit that amplifier the difference between the two signals. The differential amplifier is very useful in instrumentation circuits. The voltage V_1 and V_2 are applied at op-amp input terminals. The different voltage at the input terminal of the op-amp is zero. Node ‘a’ and ‘b’ are at the same potential designated as V_3.



R_2
R_1
−
+
v_1
R_3
v_2
R_4
$v_{OUT}=v_2\frac{R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right)-v_1\frac{R_2}{R_1}$

Consider node ‘a’,

$$\frac{V_3 - V_2}{R_1} + \frac{V_3 - V_0}{R_2} = 0$$

Consider node 'b'

$$\frac{V_3 - V_1}{R_1} + \frac{V_3}{R_2} = 0$$

Rewriting equation (a) & (b)

$$\left(\frac{1}{R_1} + \frac{1}{R_2}\right) V_3 - \frac{V_2}{R_1} = \frac{V_0}{R_2}$$

$$\left(\frac{1}{R_1} + \frac{1}{R_2}\right) V_3 - \frac{V_1}{R_1} = 0$$

Subtracting equating (3) from (4)

$$-\frac{V_2}{R_1} + \frac{V_1}{R_1} = \frac{V_0}{R_2}$$

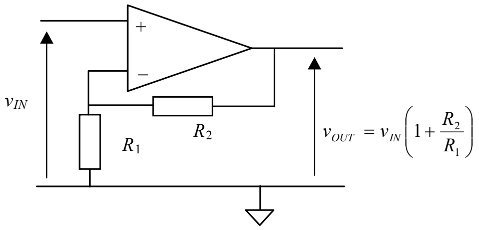
$$\frac{V_1 - V_2}{R_1} = \frac{V_0}{R_2}$$

$$V_0 = \frac{R_2}{R_1}(V_1 - V_2)$$

7. Explain the analysis of inverting amplifier and non- inverting amplifier (APRIL/2013)

(i) INVERTING AMPLIFIER

An inverting amplifier not only amplifies the input signal but also produce a phase shift in voltage between the input and the output.



Inverting Amplifier

The op amp circuit consists of a resistor R_1 and a feedback resistor R_f.R_1 is connected between the input and the inverting terminal of the op amp.The R_f is connected between the input inverting(2) terminal and the output(6) of the op amp. The non- inverting terminal (3) is grounded. The input and the output of the inverting amplifier are out of phase with each other.Since the input impedance of the op-amp is large, current cannot enter into the op-amp. So output current is same as the input current i.e. $I_1 = I_0$. The input is given to the inverting terminal and the non-inverting terminal is virtually grounded therefore the node voltage is zero.So voltage developed across R_f is equal to the output voltage Vn of the circuit.

W.K.T,

$V_i = I_1 R_1$

$I_1 = V_i / R_1$

$V_o = I_o * R_f$

$V_o = -I_1 * R_f \; (I_o = -I_1)$

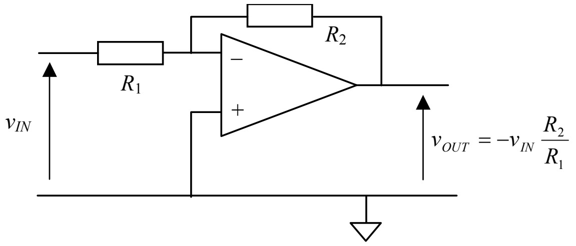
Here the –ve sign indicates that the input and the output are in the opposite direction

$V_o = -V_i * R_f / R_1$

$Av = -R_f / R_1$

(ii) NON-INVERTING AMPLIFIER:

A non-inverting amplifier amplifies the signal and the output is same as that of the input. In the non-inverting amplifier the input is applied to the non-inverting terminal (3) and the resistor R_1 is grounded. The voltage at the inverting terminal (Vi) must be same as that at the non-inverting terminal. The input impedance of the op-amp is very high so that the entire voltage given is obtained at the node 'a'.If I_1 is the current through the resistor R_1,V_i= $I_1.R_1$



Non Inverting Amplifier

Since the voltage drop across R_1 is equal to the difference between V_i and V_o,

$$I_0 = \frac{V_0 - V_i}{R_f}$$

$$I_o{*}\ R_f = V_o\text{-}V_i$$

$$V_o = V_i + I_o.{*}\ R_f$$

We know that, $I_1 = I_o$,

$$V_o = V_i + I_1.R_f$$

From (1) & (2)=

$$A_V = \frac{V_0}{V_i}$$

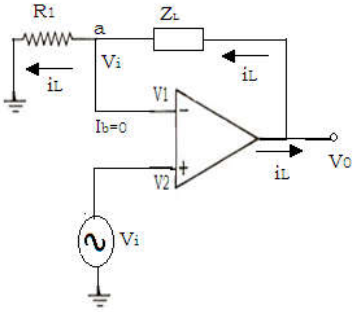
$$A_V = \frac{V_i + I_1 * R_f}{I_1 * R_1} = \frac{I_1 * R_1 + I_1 * R_f}{I_1 * R_1} = \frac{R_1 + R_f}{R_1}$$

8. Explain in detail about V to I converter. (APRIL/2012)

(i) Voltage To Current Converter [Transconductance Amplifier]

In many application it is necessary to convert voltage signal to a proportional output current.

- V- I converter with floating load
- V- I converter with grounded load



V-I Converter with Load Z_L

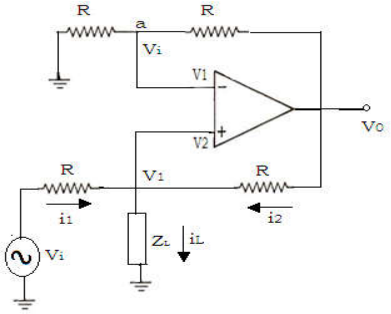
Since the voltage at node a is V_i

$$V_i = i_L R_1$$

$$i_L = \frac{V_i}{R_1}$$

(i.e.) the input voltage V_i is converted into an output current of $\frac{V_i}{R_1}$

Same current flows through signal source and load



Applying KCL, $i_1 + i_2 = i_L$

$$\frac{V_i - V_1}{R} + \frac{V_0 - V_1}{R} = i_L$$

$$\mathrm{V_i + V_0 - 2V_1 = Ri_L}$$

$$V_1 = \frac{Ri_L - V_0 - V_i}{-2}$$

$$V_1 = \frac{-Ri_L + V_0 + V_i}{2}$$

Since op-amp is used in non-inverting mode

$$\mathrm{Gain} = 1 + {}^{\mathrm{R}}/_{\mathrm{R}}$$

$$\mathrm{Gain} = 2$$

Output Voltage, $V_0 = 2V_1$

$$V_i = I_L R_1$$

$$I_L = \frac{V_i}{R_1}$$

Input impedance of non-inverting amplifier is very high.

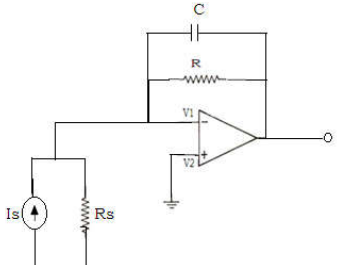
Applications:

- It is used in low voltage DC and AC voltmeter
- It is used in led and Zener diode

(ii) Current To Voltage Converter [Transresistance Amplifier]

Photocell, photodiode, photovoltaic cell give an output current, (i.e.) proportional to an incident radiant energy or light.The circuit through this device can be converted to voltage by using a current voltage converter and there by the amount of light or radiant energy incident on the photo device can be measured.-ve terminal is at virtual ground, no current flows through R_s and current Is flows through the feedback resistor R_f, thus the output voltage

$$V_0 = i_s R_f$$



Resistor R_f is sometime shunted with a capacitor C_f to reduce high frequency noise and the possibility of oscillation.

Reference:

1. *I. Albert Malvino and David Bates, "Electronic Principles", 7th Edition, Tata Mc-Graw Hill, New Delhi, 2006.*
2. *Ramakant A Gayakward, Operational Amplifiers and Linear Integrated circuits, 4th Edition, PHI Learning, Delhi, 2009.*

5. ELECTRONICS (IC 555& COUNTERS)

Advantages of ICs - pin configurations of 555 IC - Design of Astable and mono-stable multivibrator using 555 IC - Design of counters using FF-UP/DOWN counters– -Ring counters - Multiplexes –De-multiplexes

Part –A (2 Marks)

1. What do you mean by Mono-stable multi-vibrator (NOV/2014)

   A mono-stable multi-vibrator is a regenerative comparator having one stable state & one quasi stable state.
2. List the applications of 555 timer in Mono-stable mode of operation (NOV/2014)
   - Frequency doubler
   - Pulse width modulation
   - Linear ramp generator
   - Missing pulse detector.
3. What is a multi-vibrator? (APRIL/2014)

   A circuit which can oscillate at a number of frequencies is called a multivibrator.
4. Write the applications of BCD counters. (APRIL/2014)
   - Sequential generator
   - To enable interrupt in Control application
   - Used as timer
5. List the applications of counter.(NOV/2013)
   - Sequencer
   - Frequency divider,
6. List the advantage of ICs. (APRIL/2013)
   - Extremely small size
   - Very less weight
   - Reduced cost
   - High reliability
   - Low power consumption
   - Easy replacement
   - Increased response time and speed

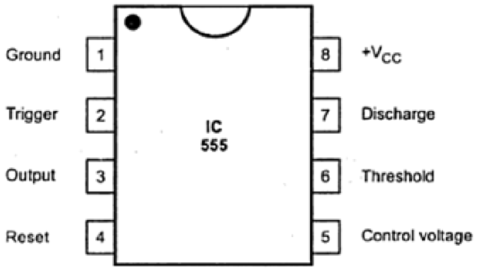
- Higher yield

7. Define shift register. (APRIL/2013)

   The binary information (data) in a register can be moved from stage to stage within the register or into or out of the register upon application of clock pulses. This type of movement or shifting is essential for certain arithmetic and logical operations used in microprocessors. This gives rise to a group of registers called shift registers.

8. Mention some applications of digital counters. (NOV/2012)
   - Alarm clock
   - Flashing indicator lights of your vehicle
   - Camera

9. Draw the pin configurations of 555 IC. (APRIL/2012) (NOV/2013)



10. What are the types of shift registers? (APRIL/2012)
    - Serial In serial out shift register
    - Serial in parallel out shift register
    - Parallel in serial out shift register
    - Parallel in parallel out shift register
    - Bidirectional shift register

Part- B (11 Marks)

INTEGRATED CIRCUIT(IC)

"An IC is an Electronic circuit in which the active and passive components are fabricated on a tiny single chip of silicon"

Advantages OF ICs

1. *Extremely small size*
   - This is thousands of times smaller than a discrete circuit.
2. *Very less weight*
   - Many circuit functions can be packed into a small space.
3. *Reduced cost*
   - The reduction in cost is due to that many identical circuits can be built simultaneously on a single wafer this process is called Batch fabrication.
4. *High reliability*
   - It is due to the absence of soldered connections
   - Higher reliability means that the ICs will work for longer period without any problem.
5. *Low power consumption*
   - Because of their small size, ICs are more suitable for low power operation.
6. *Easy replacement*
   - ICs are hardly ever repaired because in case of failures, it is more economical to replace them than to repair them.
7. *Increased response time and speed*

    - Various components of an IC are located close to each other, therefore the time delay of signals is reduced.
    - Because of the short distances, the chance of stray electrical pickup (called parasitic capacitance) is nil. As a result, the response time or the operating speed of the system is improved

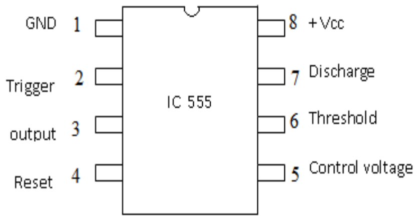
8. *Higher yield*
    - The yield is the percentage of usable devices. Due to batch fabrication, the yield is very high.

Disadvantages of IC

- It functions at fairly low voltages.
- Coils or inductors cannot be fabricated.
- Handle only limited amount of power.
- Cannot withstand rough handling or excessive heat.

1. Draw and explain the functional diagram of a 555 timer. (NOV/2012) (NOV/2014)

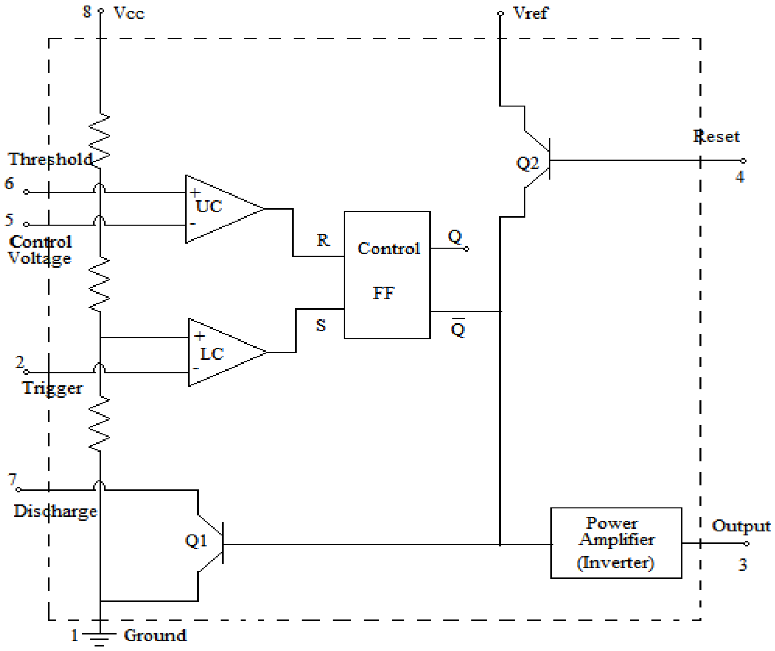
PIN CONFIGURATIONS OF IC 555



Pin diagram of IC555

Pin Functions

- **Pin: 1**: Ground (GND): All voltages are measured with respect to this terminal.
- **Pin:** 2: Trigger: It is the external input that will be applied to the inverting input of the lower comparator & will be compared with (1/3) V_{cc} coming from the potential divider network.
- **Pin:** 3: Output: Complement of the output of the flip-flop acts as the final output of timer as it passes through a power amplifier which is an inverter. Load can either be connected between pin 3 & ground or pin 3 & V_{cc}.
- **Pin**: 4: Reset: This is an input to the timing device which provides a mechanism to reset the flip-flop in a manner which overrides the effect of any instruction coming to the FF from lower comparator. This is effective when the reset input is less than 0.4V.When not used it is returned to V_{cc}.
- **Pin**: 5: Control Voltage input: Generally the fixed voltages of (1/3)V_{cc}&(2/3)V_{cc} also aid in determining the timing interval. The control voltage at 5 can be used when it is required to vary the time & also in such cases when the reference level at V- of the UC is other than 2/3Vcc.Generally when not used a capacitor of 0.01uF should be connected between 5 & ground to bypass noise or ripple from the supply.
- **Pin**: 6: Threshold: An external voltage by means of a timing capacitor & resistor is applied to this pin. When this voltage is greater than (2/)3V_{cc} output of UC is 1 which is given to the set input of FF thereby setting the FF making Q=1 & Q=0.
- **Pin**:7: Discharge: This pin is connected to the collector of the discharge transistor Q_1.When Q output of the FF is 1,then Transistor Q_1 is on due to sufficient base drive hence driving transistor into saturation. When output of the FF is low Transistor Q_1 is off hence acting as a open circuit to any external device connected to it.
- Pin: 8: +Vcc (Power Supply): It can work with any supply voltage between 5 & 18V.



Detailed Diagram of IC555

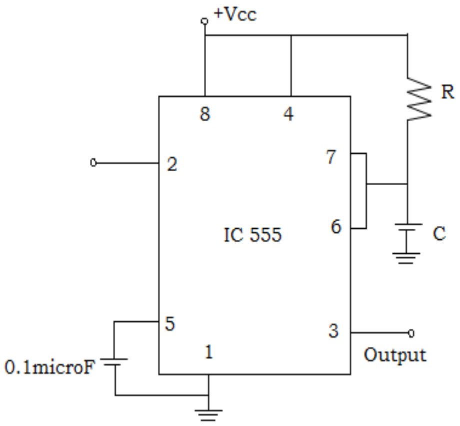
The two major applications of 555 timer are:

- Monostable multi-vibrator.
- Astable multi-vibrator.

2. Explain the operation of monostable multi-vibrator. (APRIL/2013)

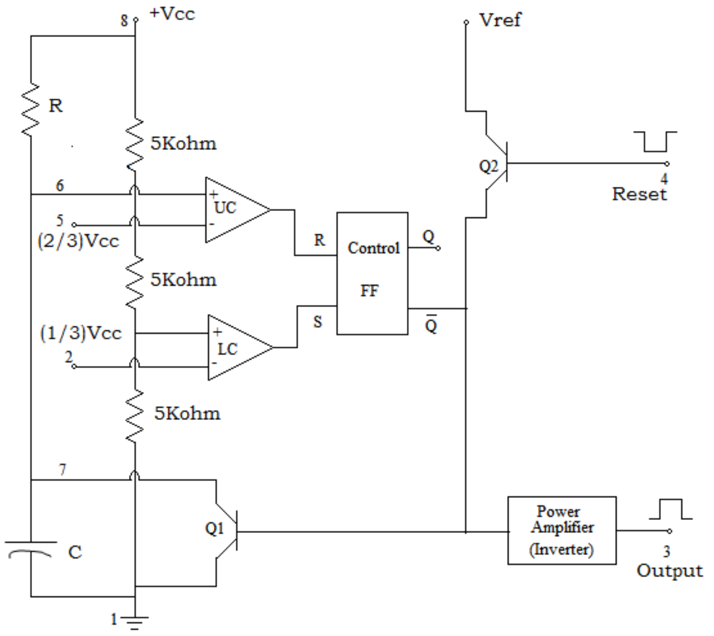
MONOSTABLE MULTIVIBRATOR

A monostable multi-vibrator is a regenerative comparator having one stable state & one quasi stable state. The IC555 timer can be operated as a monostable Multi Vibrator by connecting an external resistor & a capacitor as shown in figure below:



Pin Diagram of Monostable Multi-vibrator

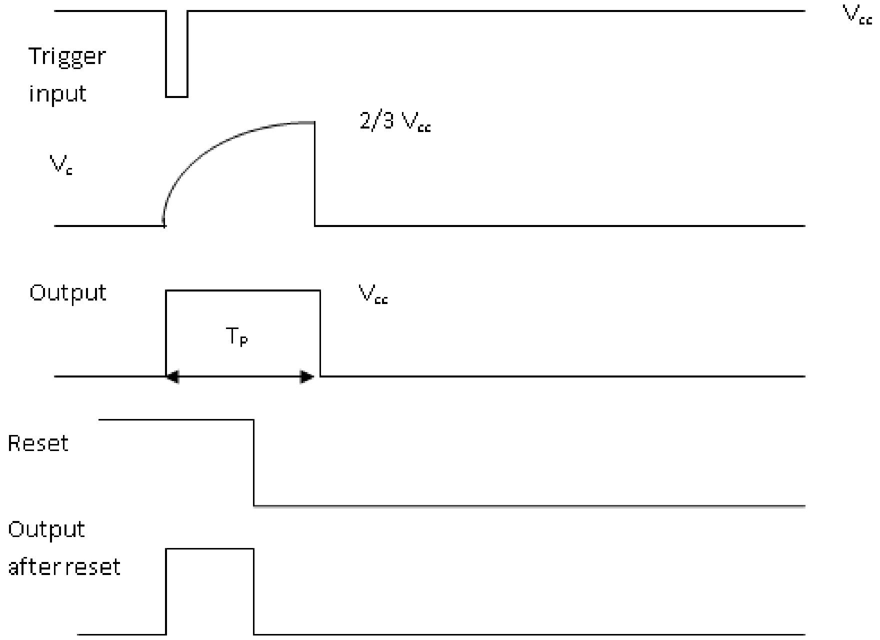
This circuit has only one stable state (0 state) .Whenever an external trigger is applied, it produces a pulse at the output & returns back to its stable state. The duration of the pulse depends on the values of R &C. It is also called as Mono shot or one shot MV.



Detailed Diagram of Monostable Multi-vibrator

Working:

Initially, let output be 0, then Q of FF is high & it holds the transistor Q1 on, thus clamping the external timing capacitor to ground. As the input trigger passes through $V_{cc}/3$, the FF is reset & hence Q=0.This makes Q_1 off & the short circuit across timing capacitor is released, & now output is high. Now the timing cycle begins, charging capacitor C towards V_{cc} through R with a time constant RC. After a time period T when the capacitor Voltage just exceeds $2/3V_{cc}$ (as compared in UC), the UC output becomes 1 & sets the FF output to 1.Therefore Q=1.Now transistor q1 turns on (saturates), thereby discharging the capacitor rapidly to ground potential. Output also returns to 0 state.



Waveforms of Monostable Multivibrator

Expression for Pulse Width:

The instantaneous Voltage across capacitor is given by,

$$V_c=V_f + (V_i - V_f)\, e^{-\tau/T_P}$$

Here V_f is the final voltage the capacitor can reach=V_{cc}

V_i is the initial voltage of the capacitor=0

$$\text{Therefore, } V_c = V_{cc}(1-e^{-t/RC})$$

But $V_c=2/3V_{cc}$ at $t=T_P$, the pulse width.

$$2/3V_{cc} = V_{cc}[1- e^{-T_P/RC}]$$

$$e^{-T_P/RC} = 1-2/3=1/3$$

$$^{-T_P/RC}=\ln(1/3)=-1.0986$$

$$T_P=1.1RC$$

Therefore Voltage across capacitor will reach $2/3V_{cc}$ in approximately 1.1RC which is also the pulse width.

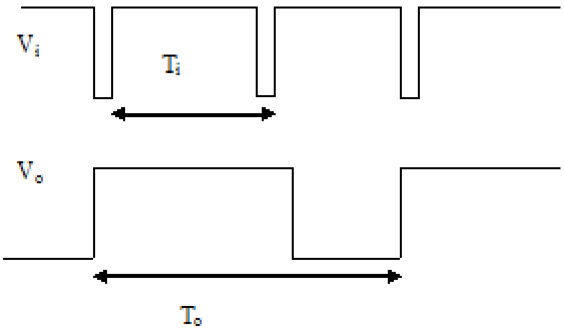
NOTE:

- Once triggered output remains in high state until the time T_P elapses which depend only on R & C. Any additional trigger pulse coming during this time will not alter the output states.
- But, if a negative going reset pulse is applied at pin 4 during the timing cycle, Q_2 turns on thereby over riding Q output of FF & Q_1 also turns on & external capacitor C is immediately discharged as shown in fig.
- Now even if Reset is released output will remain low till the next negative going trigger pulse comes along.

Applications of Monostable Multivibrator

Frequency Divider

Since the application of a trigger pulse causes output to go to high state, by adjusting time interval of input trigger to be less than the pulse width of the monostable multi-vibrator, it can be used as a frequency divider.

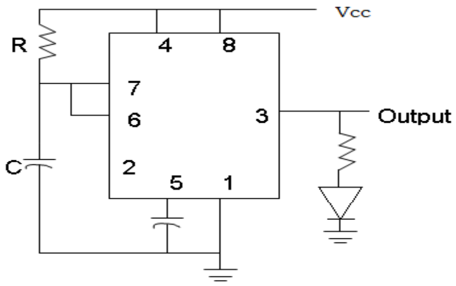


Waveform of Frequency Divider

In the above waveform $T_i>T_o$. Therefore $f_o=f_i/2$.

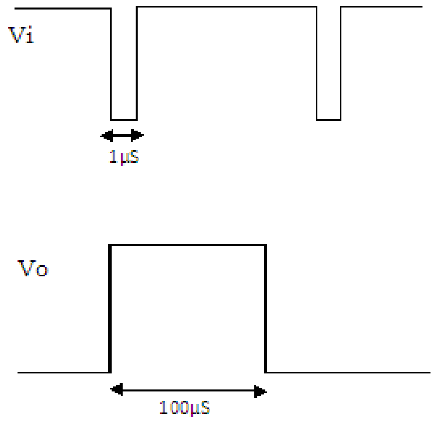
In general, if $T_i>$ (n-1) To, then $f_o= f_i/n$.

Pulse Stretcher



Pin Diagram of Pulse Stretcher

The monostable circuit shown above can also be called as a pulse stretcher if we consider its working where a narrow negative trigger pulse input is converted to a wide positive output pulse. This circuit is especially useful in LED displays where the display should be kept on for at least a sufficient duration of time so that it can be noticed by the human user (persistence of vision).The input & output pulses are as shown below:



Waveform of Pulse Stretcher

3. Draw the block diagram of an Astable multi-vibrator using 555 timer and derive an expression for its frequency of oscillation. (11) (NOV/2014)

(or)

Explain in detail about the Astable multi-vibrator. (APRIL/2012)

(or)

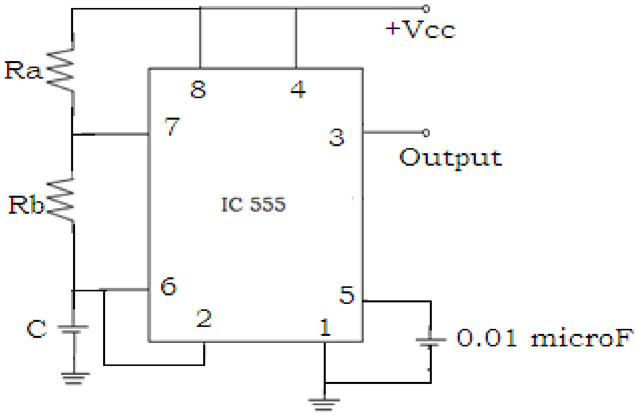
Explain the operation of Astable multi-vibrator with neat sketch. (NOV/2013)

(or)

Explain the operation of Astable multi-vibrator. (APRIL/2014)

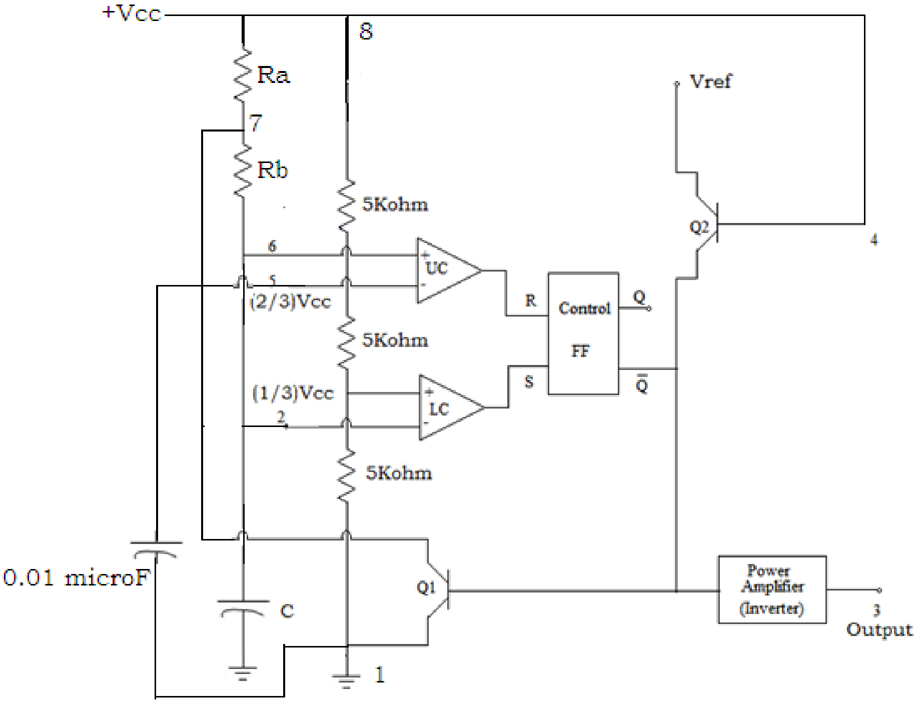
ASTABLE MULTIVIBRATOR USING IC 555

An Astable multi-vibrator is a regenerative comparator having no stable states but two quasi stable states. It is also called free-running multi-vibrator, because it does not require an external trigger pulse to change its output. The output continuously alternates between high & low states.



Pin Diagram of Astable Multi-vibrator

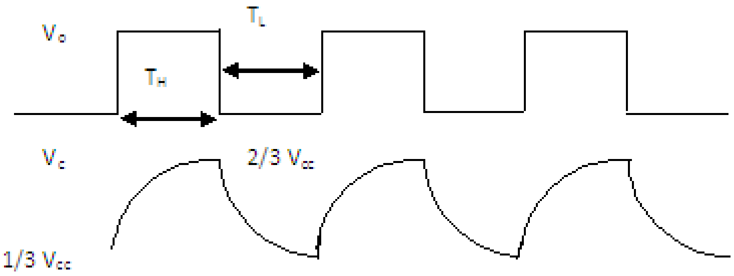
The time period for which the output remains in either of the states is determined by two timing resistors & a capacitor that are externally connected to the circuit.



Detailed Diagram of Astable Multi-vibrator

Working:

Comparing monostable operation, timing resistor is now split into two parts R_a & R_b. Pin 7, collector of discharging transistor Q1 is connected to the junction of R_a & R_b. Assume initially output is high. Output of FF, Q=0. The discharge transistor Q1 is off .Now the external timing capacitor charges towards V_{cc} with a time constant (R_a+ R_b) C. As the capacitor Voltage rises just above 2/3V_{cc}, the output of UC becomes 1 & that of LC becomes 0 thereby setting the output of control FF to 1.Hence final output at pin 3 becomes 0. Now the discharge transistor Q1 is on & the capacitor discharges with a time constant (R_b)C.As the capacitor voltage just reaches below 1/3V_{cc} LC is triggered on & output of UC becomes 0 thereby making the output of FF 0 & final output high. This unclamps the timing capacitor C which now starts getting charged again repetitively.



Waveforms of Astable Multivbrator

Expression for T

The instantaneous voltage across the capacitor is given by,

$$V_c=V_f + (V_i - V_f)e^{-\tau/T}$$

Here, *V_f is the final voltage the capacitor can reach*

V_i is the initial voltage of the capacitor

Consider the charging time of capacitor as T_C

Now for charging,

$$V_f=V_{cc} \& V_i=1/3V_{cc}$$

Therefore,

$$V_c=V_{cc}+(1/3V_{cc}-V_{cc})\,e^{-t/(Ra+Rb)C}$$

But

$$V_c=2/3V_{cc} \text{ at } t=T_C\text{, the charging time.}$$

Therefore,

$$2/3V_{cc}=V_{cc}+(1/3V_{cc}-V_{cc})\,e^{-T_C/(Ra+Rb)C}$$

$$1/3V_{cc}=2/3V_{cc}e^{-T_C/(Ra+Rb)C}$$

$$e^{-T_C/(Ra+Rb)C}=1/2$$

$$T_C/(Ra+Rb)C=0.693$$

$$T_C=0.693(R_a+R_b)C$$

Now consider the discharging time of capacitor as T_D

For discharging,

$$V_f=0 \;\&\; V_i=2/3V_{cc}$$

Therefore,

$$V_c=0+(2/3V_{cc}-0)\,e^{-t/RbC}$$

But

$$V_c=1/3V_{cc} \text{ at } t=T_D\text{, the discharging time.}$$

Therefore,

$$1/3V_{cc}=0+(2/3V_{cc}-0)e^{-T_D/RbC}$$

$$e^{-T_D/RbC}=1/2$$

$$T_D/R_bC=0.693$$

$$T_D=0.693R_bC$$

$$T=T_C+T_D$$

$$T=0.693(R_a+2R_b)\,C$$

$$f=1/T=1.45/(R_a+2R_b)C$$

Duty Cycle

The ratio of the time duration for which the output is high to the total time period T is called the duty cycle of the Astable multi-vibrator denoted by D.

$$D=T_C/T$$

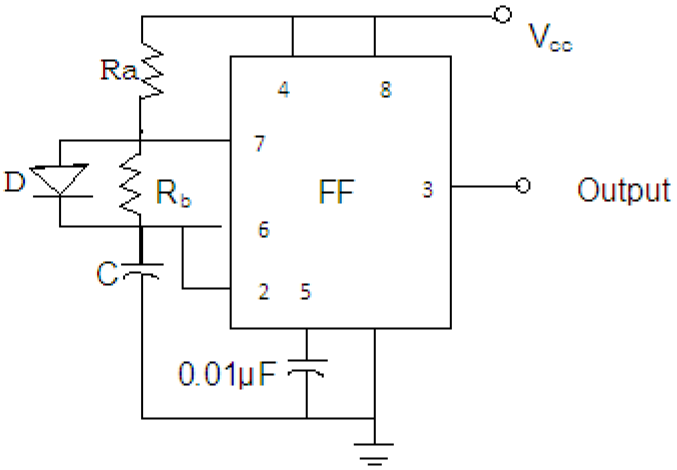
$$D=(R_a+R_b)/(R_a+2R_b)$$

NOTE:

D can never be equal to or less than 0.5 for any combination of R_a & R_b ,& it is always greater than 0.5

To obtain a duty cycle of 50%, $R_a=0$ which results in an additional current through transistor Q1 hence damaging the transistor.

However there is an alternate solution to this problem. A switching diode is connected in parallel with R_b as shown in figure below.



Astable Multi-vibrator with Diode

In the above circuit, during the charging interval of the capacitor the diode is forward biased, it conducts & bypasses R_b. So the capacitor charges through R_a& diode D. But, as before it discharges through R_b. Then assuming ideal diode the charging & discharging intervals of the capacitor are:

$$T_C=0.693R_aC$$

$$T_C=0.693R_bC$$

$$T= 0.693(R_a+R_b)\ C$$

$$D= D=T_C/T = (R_a)/\ (R_a+R_b)$$

If we set $R_a=R_b$, we get a duty cycle of 50% & a symmetrical square wave at the output.

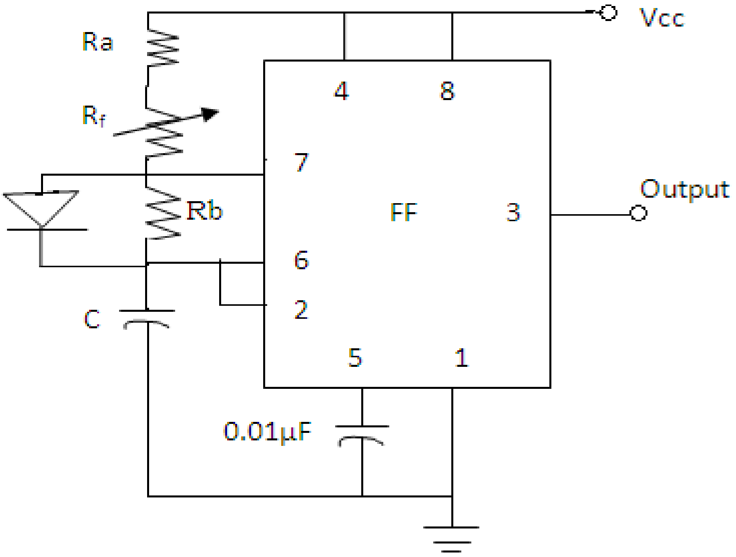
Design considerations for Monostable & Astable Multivibrators

- The timing capacitance should be larger than 500pF to keep stray capacitances negligible.
- The resistors should be greater than 1KΩ to limit the current & should not be larger than 3.3MΩ (the sum in case of Astable)
- Maximum frequency of oscillation is limited to 1MHz.

APPLICATIONS OF 555 ASTABLE MULTIVIBRATOR

Square Wave Generator

An astable multivibrator can be used as a square wave generator. To obtain a symmetrical square wave with 50% duty cycle the following circuit can be used. Here the capacitor charges through R_a & the forward biased diode D & discharges through R_b.In order to make the charging & discharging times equal, the resistance R_a is constructed with a fixed resistance in series with a potentiometer as shown in figure, so that the potentiometer can be adjusted to get $R_a+R_f=R_b$ in order to obtain an exact symmetrical square wave output where R_f is the forward resistance of the diode



Square Wave Generator

Free Running ramp Generator

The 555 Astable multi-vibrators can be used to generate a free running ramp by replacing the timing resistors R_a & R_b with a current mirror as shown below. Here the current mirror acts as a constant current source & charges the capacitor C linearly towards V_{cc}. When the capacitor voltage rises above $2/3V_{cc}$ the UC sets the FF output to 1 which in turn turns on the discharge transistor Q1 on. Thus, the capacitor discharges rapidly through transistor Q1.When the capacitor voltage drops below 1/3vcc LC output resets the FF output to 0 which causes the discharge transistor to turn off & as a result the capacitor C begins to charge again.

The charging & discharging of the capacitor repeats continually resulting in the waveform shown in fig. Also $T_c>>T_D$ because the capacitor discharges through the on transistor whose resistance is very small. Hence $T=T_c$. During the charging time Tc, the capacitor voltage changes by $1/3V_{cc}$ due to the flow of the constant current I_c. The charge acquired by the capacitor C as a result of the constant current I_c flowing for a time t_c is given by,

$$Q=I_c t_c$$

The charge acquired by a capacitor of capacitance C is also given by

$$Q=CV$$

Where, V is the change in voltage across the capacitor.

In this case, since $V=1/3V_{cc}$ we have

$$Q=1/3V_{cc}$$

Hence, from equations (13) & (14), we get

$$t_c I_c=1/3V_{cc}C$$

The period of the free running ramp is $T=t_c$& therefore,

$$T=t_c=V_{cc}C/3I_c$$

Where the constant current I_c is given by,

$$I_c=V_{cc}-V_{BE}/R$$

The free running frequency of the ramp generator is thus

$$f=1/T=3I_c/V_{cc}\,C$$

4. Design a monostable multi-vibrator for a pulse width of 1ms.

T_P=1ms=1.1RC

Let C=0.1µF

Then R=1ms/ $(1.1*0.1*10^{-6})$ = 9.1KΩ

5. A 555 monostable multi-vibrator is used to divide a 1 KHz input signal by 3.If R=20K, calculate the required value of C.

The period of the trigger input signal is

T_t=1/1 KHz = 1ms.

For a divide by 3 circuit, T_P should be greater than $2T_t$ but less than $3T_t$.Let us take $T_P=2.2T_t$

Therefore T_P=2.2*1ms=2.2ms

Thus $C=T_P/1.1R=2.2*10^{-3}/1.1*20*10^{3}$=0.1µF

6. Design a 555 mono-stable circuit that stretches the width of a narrow pulse from 1µs to 100µs.

The width TP of the mono-stable output should be 100µs.Therefore,

$RC=T_P/1.1=100*10^{-6}/1.1=90.9*10^{-6}$

Let C=0.1µF, we have

$R=90.9*10^{-6}/C = 90.9*10^{-6}/0.1*10^{-6}$ =909Ω.

7. Design a 555 timer astable multivibrator for an output frequency of 1 KHz & duty cycle of 60%.

T = 1/f = 1/1 KHz = 1ms

T_C=TD=0.6*1ms=0.6ms

$T_D=T- T_C$ = (1-0.6)ms=0.4ms

$R_b=T_D/0.693C$

Let C=0.1µF

Therefore $R_b=0.4*10^{-3}/0.693*0.1*10^{-6}$ = 5.77K Ω

$R_a=T_C/0.693C - R_b$

3.06K Ω.

8. What is meant by counters and explain any one type of counters

COUNTERS

A counter is a device which stores (and sometimes displays) the number of times a particular event or process has occurred, often in relationship to a clock signal. In practice, there are two types of counters:

- Up counters, which increase (increment) in value
- Down counters, which decrease (decrement) in value

Counters can be implemented easily using register-type circuits such as the flip-flop. The types of counters are

- Asynchronous (ripple) counter – changing state bits are used as clocks to subsequent state flip-flops
- Synchronous counter – all state bits change under control of a single clock
- Decade counter – counts through ten states per stage
- Up–down counter – counts both up and down, under command of a control input
- Ring counter – formed by a shift register with feedback connection in a ring
- Johnson counter – a twisted ring counter
- Cascaded counter

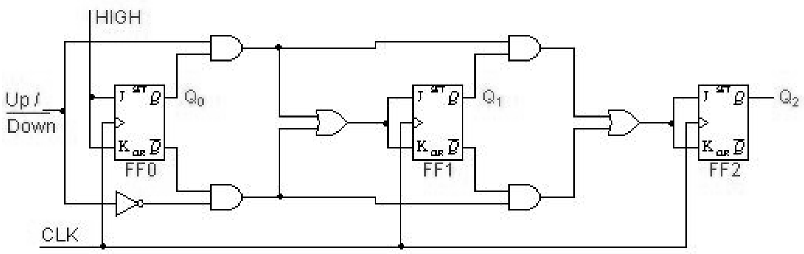
9. Explain the operation of UP/DOWN counter (APRIL/2012)

(or)

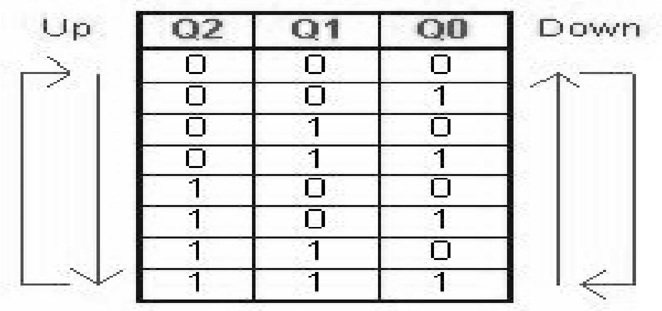
Draw and explain the operation and truth table of UP-DOWN counter. (APRIL/2013)

Up Down counters

A circuit of a 3-bit synchronous up-down counter and a table of its sequence are shown below. It is used to control the direction of the counter through a certain sequence.



Synchronous counter



Q2	Q1	Q0
0	0	0
0	0	1
0	1	0
0	1	1
1	0	0
1	0	1
1	1	0
1	1	1

Bit Sequence

- For both the UP and DOWN sequences, Q0 toggles on each clock pulse.
- For the UP sequence, Q1 changes state on the next clock pulse when Q0=1.
- For the DOWN sequence, Q1 changes state on the next clock pulse when Q0=0.
- For the UP sequence, Q2 changes state on the next clock pulse when Q0=Q1=1.
- For the DOWN sequence, Q2 changes state on the next clock pulse when Q0=Q1=0.

These characteristics are implemented with the AND, OR & NOT logic connected as shown in the logic diagram above.

10. Draw and explain the operation of shift registers. (APRIL/2014) (NOV/2013)

Shift registers

In digital circuits, a shift register is a cascade of flip flops, sharing the same clock, which has the output of anyone but the last flip-flop connected to the "data" input of the next one in the chain, resulting in a circuit that shifts by one position the one-dimensional "bit array" stored in it, shifting in the data present at its input and shifting out the last bit in the array, when enabled to do so by a transition of the clock input. A shift register may be multidimensional; such that its "data in" input and stage outputs are themselves bit arrays: this is implemented simply by running several shift registers of the same bit-length in parallel. Shift registers can have both parallel and serial inputs and outputs. These are often configured as serial-in, parallel-out (SIPO) or as parallel-in, serial-out (PISO). There are also types that have both serial and parallel input and types with serial and parallel output. There are also bi-directional shift registers which allow shifting in both directions: L→R or R→L. The serial input and last output of a shift register can also be connected together to create a circular shift register.

11. Explain the working of serial in – serial out shift register with logic diagram. (NOV/2012)

Serial-In, Serial-Out (SISO)

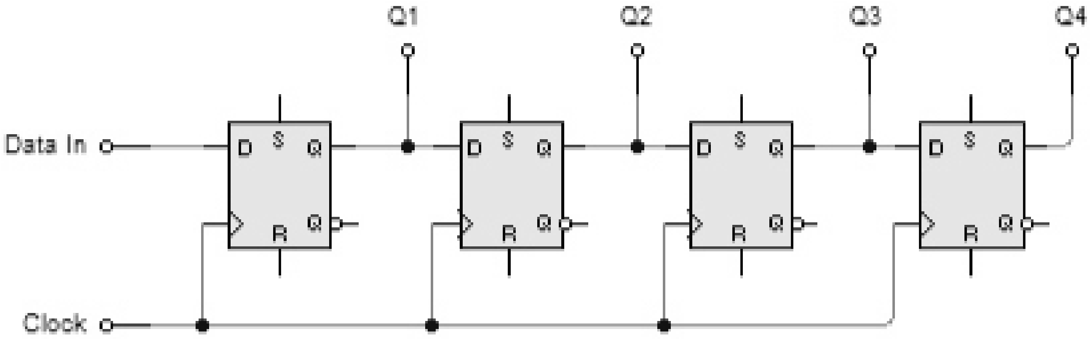
Serial-IN Serial-OUT register is simplest kind of shift registers. The data string is presented at 'Data In', and is shifted right one stage each time 'Data Advance' is brought high. At each advance, the bit on the far left (i.e. 'Data In') is shifted into the first flip-flop's output. The bit on the far right (i.e. 'Data Out') is shifted out and lost. The data are stored after each flip-flop on the 'Q' output, so there are four storage 'slots' available in this arrangement; hence it is a 4-Bit Register. To give an idea of the shifting pattern, imagine that the register holds 0000 (so all storage slots are empty). As 'Data In' presents 1,0,1,1,0,0,0,0 (in that order, with a pulse at 'Data Advance' each time. This is called clocking or strobing) to the register, this is the result. The left hand column corresponds to the left-most flip-flop's output pin, and so on. So the serial output of the entire register is 10110000.

0	0	0	0
1	0	0	0
0	1	0	0
1	0	1	0
1	1	0	1
0	1	1	0
0	0	1	1
0	0	0	1
0	0	0	0

4 Bit Sequence of Serial In Serial Out Shift Register

Serial-In, Parallel-Out (SIPO):

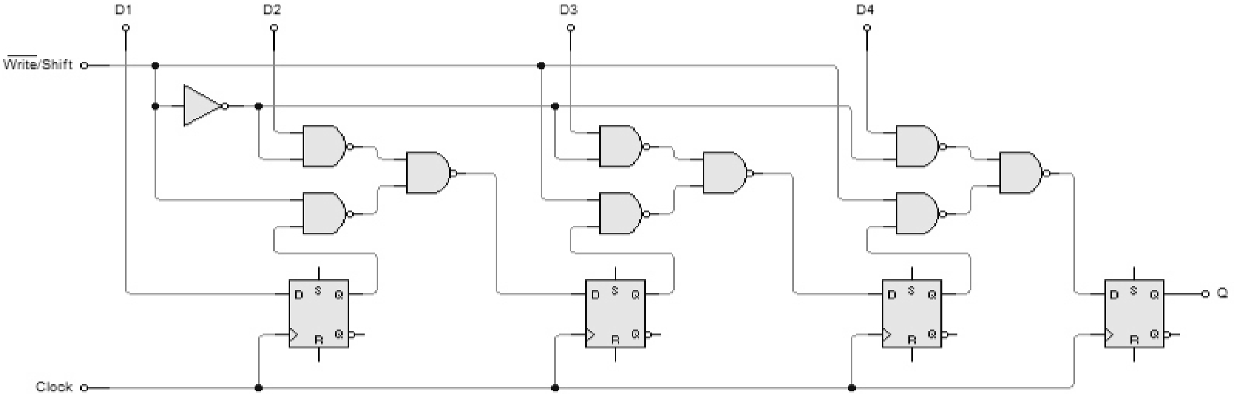
This configuration allows conversion from serial to parallel format. Data is input serially. Once the data has been input, it may be either read off at each output simultaneously, or it can be shifted out and replaced.



4-Bit SIPO Shift Register

Parallel-In, Serial-Out (PISO)

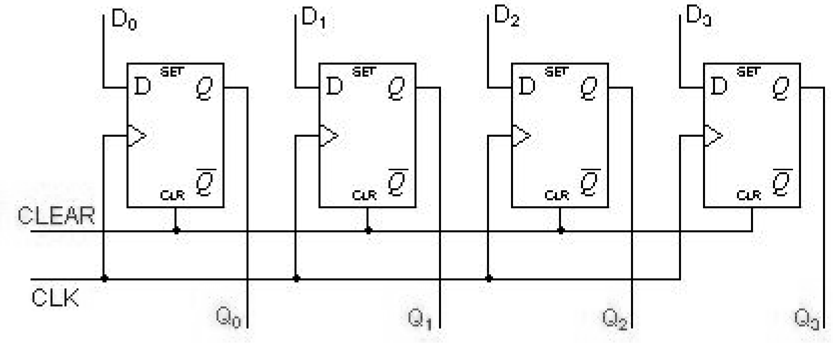
This configuration has the data input on lines D1 through D4 in parallel format. To write the data to the register, the Write/Shift control line must be held LOW. To shift the data, the Write/Shift control line is brought HIGH and the registers are clocked. The arrangement now acts as a PISO shift register, with D1 as the Data Input. However, as long as the number of clock cycles is not more than the length of the data-string, the Data Output, Q, will be the parallel data read off in order.



4 Bit Parallel In Serial Out Shift Register

Parallel In Parallel Out Register

For parallel in - parallel out shift registers, all data bits appear on the parallel outputs immediately following the simultaneous entry of the data bits. The following circuit is a four-bit parallel in - parallel out shift register constructed by D flip-flops.



4Bit Parallel Bit Parallel Out Shift Register

The D's are the parallel inputs and the Q's are the parallel outputs. Once the register is clocked, all the data at the D inputs appear at the corresponding Q outputs simultaneously.

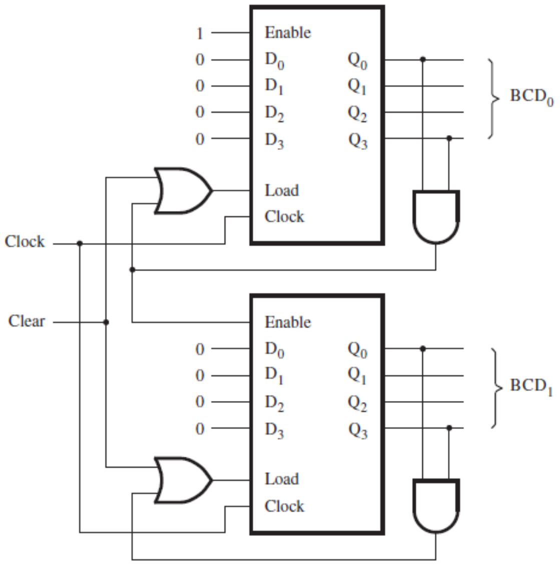
Applications:

- One of the most common uses of a shift register is to convert between serial and parallel interfaces. This is useful as many circuits work on groups of bits in parallel, but serial interfaces are simpler to construct. Shift registers can be used as simple delay circuits. Several bi-directional shift registers could also be connected in parallel for a hardware implementation of a stack.
- Shift registers can be used also as pulse extenders. Compared to monostable multi-vibrators the timing has no dependency on component values, however requires external clock and the timing accuracy is limited by a granularity of this clock.
- shift registers were used to handle data processing: two numbers to be added were stored in two shift registers and clocked out into an arithmetic and logic unit (ALU) with the result being fed back to the input of one of the shift registers (the Accumulator) which was one bit longer since binary addition can only result in an answer that is the same size or one bit longer.
- Many computer languages include instructions to 'shift right' and 'shift left' the data in a register, effectively dividing by two or multiplying by two for each place shifted.

12. Explain in detail about BCD counter

BCD Counter

Binary-coded-decimal (BCD) counters consists of two modulo-10 counters, one for each BCD digit, implemented using the parallel load four-bit counter. It is necessary to reset the four flip-flops after the count of 9 has been obtained. Thus the Load input to each stage is equal to 1 when Q3 = Q0 = 1, which causes 0s to be loaded into the flip-flops at the next positive edge of the clock signal. Whenever the count in stage 0, *BCD* 0, reaches 9 it is necessary to enable the second stage so that it will be incremented when the next clock pulse arrives.



BCD Counter

This is accomplished by keeping the Enable signal for *BCD*1 low at all times except when *BCD*0 = 9. It has to be possible to clear the contents of the counter by activating some control signal. Two OR gates are included in the circuit for this purpose. The control input clear can be used to load 0s into the counter. Clear is active when high. In any digital system there is usually one or more clock signals used to drive all synchronous circuitry. Counters can be used to count the number of pulses in any signal that may be used in place of the clock signal.

13. Explain in detail about Multiplexor and Demultiplexor

Multiplexors

***"The multiplexor (mux), provides the function of a rotary switch, selecting one of several inputs to connect to a single output. The multiplexor is often referred to as a selector*."**

A mux acts like a rotary switch connecting one of several inputs to a single output. The selection of which input to connect to the output is determined by additional inputs called select or control lines. The input selected is determined by the binary equivalent of the value placed on the select lines. For example, consider a mux that selects one of four inputs to connect to the output. This is referred to as a 4-to-l mux. To select one of four inputs, there must be four unique combination of the select lines. This requires two select lines providing the four unique combinations 00, 01, 10, and 11. A select-line combination of 00 would select input 0, select-line combination 01 would select input I, and so on.

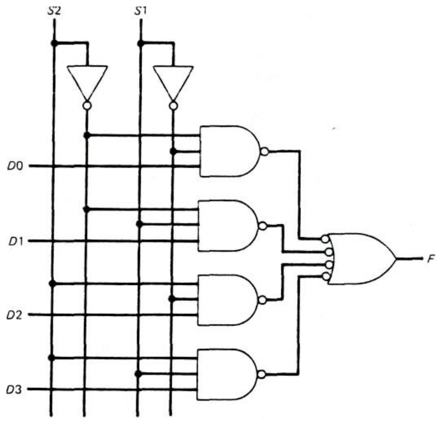
S1	S2	F
0	0	D0
0	1	D1
1	0	D2
1	1	D3

4-to-1 Mux Truth Table

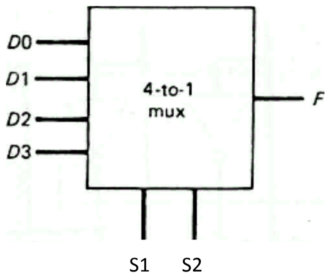
The function of the multiplexor is illustrated in the truth table shown in the above table. This truth table shows the output F as a function of the select-line inputs. Instead of listing all possible states of the data inputs, this simplified form of a truth table show the output as the data from input line 0 (DO), or input line 1 (D 1), and so on. As can be seen from the above table, we want to pass DO when 5'2 and 5'! are both 0. Likewise, we want to pass D 1 when 52 is 0 and S1 is 1, and so on for the remaining input combinations. This is implemented by the following expression:

$$F = \overline{S2}.\overline{S1}.DO + \overline{S2}.S1.DI + S2.\overline{S1}D2 + S2.S1.D3$$

The figure shown below is a NAND-gate implementation of a 4-to-l multiplexor. To better illustrate the function of the multiplexor as a complete "unit," all variable complement! have been generated internally. Since the multiplexor function is so useful, many TTL chips exist that perform the equivalent operation of the circuit shown in below figure. For example, the 7415; contains two 4-to-l multiplexors, the 74151 contains one 8-to-l multiplexor, and the(74157 contains four 2-to-l multiplexors. A multiplexor is typically shown in a circuit as a single functional unit, not as the gates comprising the circuit. A typical representation of a 4-to-l multiplexor is shown in below figure.



4-to-l Mux Implementation



4-to-l Mux Representation

The Demultiplexor

“The demultiplexor (demux), provides the inverse function, connecting a single input to one of several outputs. The demultiplexor is often referred to as a decoder.”

The demultiplexer connects one input to one of several outputs. The output is selected via select lines as it is with the mux. The most common use of a demultiplexer is as a decoder. In fact, demuxes are typically referred to as decoders. A decoder sets the output line selected by the select lines to 0. This function is easily implemented with the demux by tying the data input line to 0.

To illustrate the behavior of a demux, consider the operation of a demux that connects one input to one of four outputs. This is referred to as a l-to-4 demultiplexer. Used as a decoder, it is referred to as a 2-to-4 decoder since two select lines select one of four outputs. The operation of this demux is illustrated in the below table. This truth table shows the four outputs of the demux as a function of the data in D 1 and select lines.

Notice that the default state of an output is 1. Therefore, any outputs not selected will be 1. Thus, as table shown below illustrates, when the data in D1 input is 1, all outputs will be 1 regardless of the select-line combination.

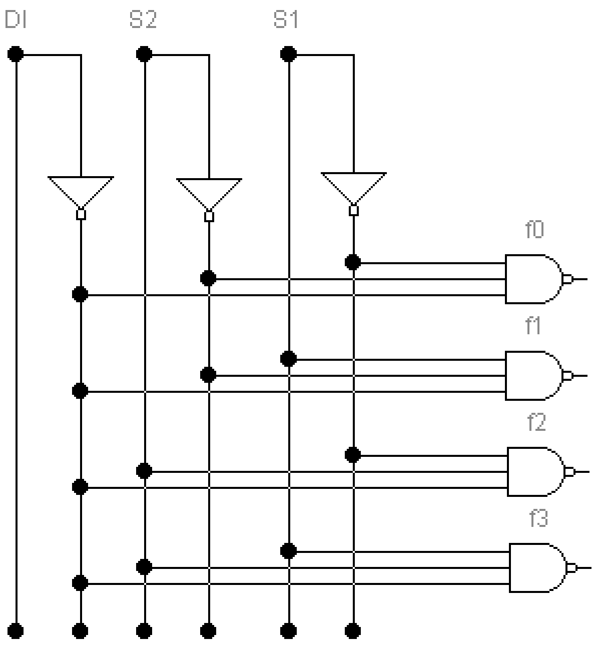
A decoder sets the output selected by the select-line inputs to 0. As can be seen in the below table, this is accomplished by tying the data input to 0. Thus the data input can be thought of as an active-low enable for the decoder. If this enable is not low, the decoder will not function (all outputs will always be 1). Often decoders will have more than one enable line, requiring all enable lines to be properly enabled before the decoder functions.

The functions illustrated in the below table can be expressed algebraically as:

FO = $\overline{\overline{D1}}\,\overline{\overline{S2}}\,\overline{\overline{S1}}$
F1 = $\overline{\overline{D1}}\,\overline{\overline{S2}}\,\overline{S1}$
F2 = $\overline{\overline{D1}}\,\overline{S2}\,\overline{\overline{S1}}$
F3 = $\overline{\overline{D1}}\,\overline{S2}\,\overline{S1}$

D1	S2	S1	F0	F1	F2	F3
0	0	0	0	1	1	1
0	0	1	1	0	1	1
0	1	0	1	1	0	1
0	1	1	1	1	1	0
1	X	X	1	1	1	1

l-to-4 Demux Truth Table



l-to-4 Demux Implementation

The figure shown above is a NAND-gate implementation of the l-to-4 demux (2-to-4 decoder). As with multiplexors, the demultiplexor circuit is available in several variations on standard TTL chips. For example, the 74138 contains one l-to-8 demux (3-to-8 decoder), and the 74139 contains two l-to-4 demuxes (2-to-4 decoders).

As with the multiplexor, a demux is typically shown in a circuit as a separate functional unit, not as the gates comprising the demux. Shown in the above figure are typical demux and decoder representations of the circuit in figure. Note the presence of active-low indicators at the enable input and each of the outputs on the decoder representation. This indicates the decoder is enabled with a low input, and an output is set to low when selected.

Applications of MUX and DEMUX

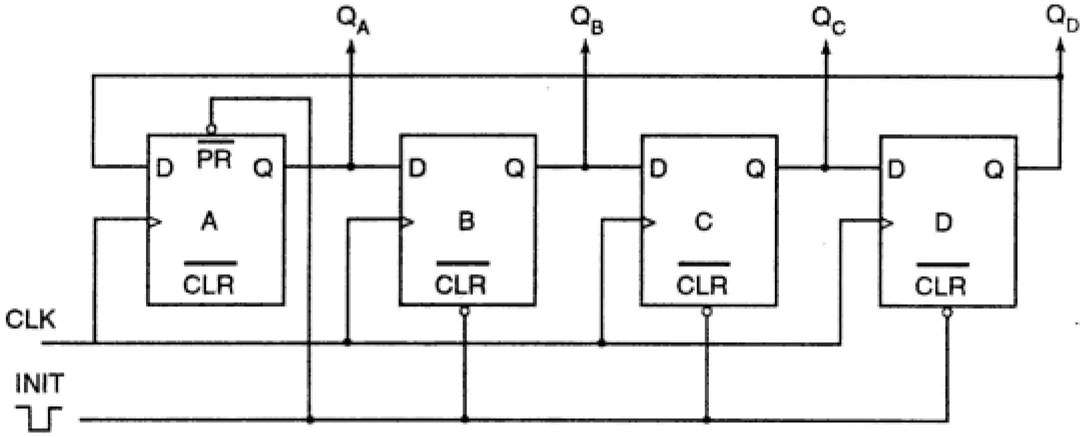
Used in tandem, a mux-demux combination can be used for serial communication to reduce the number of wires required to pass data. The pair can be used in a similar manner to run multidigital displays such as those found in calculators. Muxes are often used in digital circuits to control signal and data routing. For example, a multiplexor can be used to select the input to a particular register from one of several sources. Decoders are often used in computers to provide address decoding. Based on certain address lines, the decoder can provide enable signals to the proper memory chips. In addition, both muxes and demuxes can be used to evaluate simple boolean expressions using less hardware than if individual logic gates were used.

14. Explain about ring counter with neat diagram.

Ring counter

In a ring counter, the true output (Q) of the last flip-flop in a shift register is connected back to the serial input of the first flip-flop, and also only one flip-flop is set at any particular time while all others are cleared. The flip-flops are connected in such a way the information shifts either from left to right and back around from Q_D to Q_A or from right to left and back around from Q_A to Q_D. Single a single 1 in the register is made to circulate around the register as long as clock pulses are applied, it is called ring counter.

A 4- bit ring counter using D flip-flops is shown in the below figure. This circuit consists of four D flip-flops and their outputs are Q_A, Q_B, Q_C and Q_D respectively. The PRE-SET input of first flip-flops and CLEAR inputs of the other three flip-flops are connected together and brought out as INIT input. Now, on applying a LOW pulse at this INIT input, the first flip-flop is SET to 1 and the other three flip-flops are cleared to 0, i.e. $Q_AQ_BQ_CQ_D$ = 1000. Now, from this circuit it is clear that D_A= 0, D_B = 0, D_C = 0 and D_D = 0. Therefore, when a clock pulse is applied, the second flip-flop is set to 1 while the other three flip-flops are reset to 0, i.e. the output of the ring counter $Q_AQ_BQ_CQ_D$ = 0100. As a result, on the occurrence of the first clock pulse, the 1 in the first flip-flop shifted to the second flip-flop. Similarly, when the second clock pulse is applied, the 1 in the second flip-flop is shifted to the third flip-flop and the ring counter output $Q_AQ_BQ_CQ_D$ = 0010; on the occurrence of the fourth clock pulse, the output will be $Q_AQ_BQ_CQ_D$ = 0001; on the fifth clock pulse, $Q_AQ_BQ_CQ_D$ = 1000, i.e. the initial state. Thus, 1 is shifted or circulated around the register as long as clock pulses are applied. The truth table which describes the operation of the above 4-bit ring counter is shown in the table.



A 4 –bit counter using D- flip-flop

INIT	CLK	Q_A	Q_B	Q_C	Q_D
L	X	1	0	0	0
H	↑	0	1	0	0
H	↑	0	0	1	0
H	↑	0	0	0	1
H	↑	1	0	0	0

Truth table for 4-bit ring counter

As shown in the above truth table, the ring counter has only 4 valid states, i.e. 1000, 0100, 0010 and 0001. The ring counter can hang or enter into anyone of the invalid state due to noise or any other condition without returning to the main counting sequence. Hence, it is a must to design ring counters which are self- correcting and capable of recovering from invalid states to valid states.

Reference:

1. *I. Albert Malvino and David Bates, "Electronic Principles", 7th Edition, Tata Mc-Graw Hill, New Delhi, 2006.*
2. *Ramakant A Gayakward, Operational Amplifiers and Linear Integrated circuits, 4th Edition, PHI Learning, Delhi, 2009.*

MET35 --- ELECTRICAL AND ELECTRONICS ENGINEERING

UNIVERSITY QUESTION PAPER

Part –A

Unit -1

1. Why transformer rating is expressed in terms of KVA (NOV-2014)
2. Does transformer draw any current when secondary is open? Why? (NOV-2014)
3. The no-load ratio of a 50HZ, single phase transformer is 6000/250V. Estimate the number of turns in each winding if maximum flux is 0.06Wb in the core.(APRIL-2014)
4. Define voltage regulation of a transformer.(APRIL-2014)
5. A 220/110 V, 50 Hz ideal transformer has 166 turns in its primary. What is the peak value of flux(NOV/2013)
6. Write down the condition for maximum efficiency of the transformer(NOV-2013)
7. Define transformation ratio. (APRIL/2013)
8. State the condition for maximum efficiency of a transformer. (APRIL/2013)
9. Classify the transformer according to the construction(NOV/2012)
10. What are the advantages of three phase transformer?(NOV/2012)
11. Define a transformer. (APRIL/2012)
12. Mention some applications of an auto transformer. (APRIL/2012)

Unit -2

1. What is the function of capacitor in a single phase induction motor (NOV/2014)
2. What are the classifications of three phase induction motor based on the method of construction (NOV/2014)
3. What is Slip?(APRIL/2014)
4. Mention the methods available to make single phase induction motors self-starting(APRIL/2014)
5. A 6 pole, 50 Hz, three phase induction motor runs at 800 rpm at full load. Determine the value of slip at this load condition.(NOV/2013)
6. Mention some applications of AC series motor(NOV/2013)
7. What are the advantages of three phase induction motor? (APRIL/2013)
8. Mention the types of stepper motor. (APRIL/2013)
9. Compare squirrel cage rotor and slip ring rotor. (NOV/2012)
10. What are the classifications of single phase induction motor based on the method of starting(NOV/2012)
11. Define slip of an induction motor. (APRIL/2012)
12. What are the different types of single phase induction motor? (APRIL/2012)

Unit-3

1. Write down the equation for frequency of emf induced in an alternator (NOV/2014)

2. Name the types of alternator based on their rotor construction (NOV/2014)
3. Calculate the synchronous speed of a four pole 50Hz alternator. (APRIL/2014)
4. Write the emf equation of an alternator.(APRIL/2014)
5. Differentiate salient pole rotor and smooth cylindrical type rotor of an alternator(NOV/2013)
6. List the various losses in an alternator (NOV/2013)
7. What is the principle of operation of an alternator? (APRIL/2013)
8. Define voltage regulation. (APRIL/2013)
9. What is meant by synchronous reactance? (NOV/2012)
10. What are the losses in an alternator? (NOV/2012)
11. Differentiate salient pole rotor and smooth cylindrical type rotor. (APRIL/2012)
12. Define voltage regulation of an alternator. (APRIL/2012)

Unit-4

1. List out the ideal characteristics of OPAMP (NOV/2014)
2. Mention some of the linear applications of OPAMP (NOV/2014)
3. What are the characteristics of ideal operational amplifier? (APRIL/2014)
4. What do you mean by inverting amplifier?(APRIL/2014)
5. What is an operational amplifier(NOV/2013)
6. Draw the circuit diagram of I to V converter(NOV/2013)
7. What are the characteristics of ideal operational amplifier? (APRIL/2013)
8. Draw the circuit diagram of subtractor. (APRIL/2013)
9. Draw the circuit diagram of op-amp differentiator. (NOV/2012)
10. What is meant by filter? (NOV/2012)
11. What is an inverting amplifier? (APRIL/2012)
12. Mention some applications of an instrumentation amplifier. (APRIL/2012)

Unit -5

1. What do you mean by Mono-stable multi-vibrator (NOV/2014)
2. List the applications of 555 timer in Mono-stable mode of operation (NOV/2014)
3. What is a multivibrator? (APRIL/2014)
4. Write the applications of BCD counters. (APRIL/2014)
5. Draw the pin diagram of 555 IC(NOV/2013)
6. List the applications of counter.(NOV/2013)
7. List the advantage of ICs. (APRIL/2013)
8. Define shift register. (APRIL/2013)
9. What are the operating modes of multivibrator? (NOV/2012)
10. Mention some applications of digital counters. (NOV/2012)
11. Draw the pin configurations of 555 IC. (APRIL/2012)
12. What are the types of shift registers? (APRIL/2012)

Part- B

Unit-1

1. Describe the construction details of transformer and also explain the principle of operation with necessary diagram (11) (NOV/2014)

2. (a) Derive the emf equation of a transformer (5) (NOV/2014)
   (b) A single phase transformer has 400 primary turns and 1000 secondary turns. The net cross sectional area of the core is 60 cm^2, if the primary winding is connected to 50Hz supply at 500 V. Calculate the value of maximum flux density in the core and the emf induced in the secondary winding. (6)(NOV/2014)
3. (a)Derive the emf equation of a transformer (APRIL/2014)
   (b) A 600KVA, single phase transformer when working at UPF has an efficiency of 92% at full load. Determine the efficiency when it operates at UPF and 60% of full load (APRIL/2014)
4. (a)Obtain the equivalent circuit of a transformer. (APRIL/2014)
   (b) Derive the condition for maximum efficiency of a transformer. (APRIL/2014)
5. Obtain the approximate equivalent circuit of a given 200/ 2000 V, single phase 25 kVA transformer having the following test results(NOV/2013)
   O.C. Test: 200 V, 6 A, 350 W on L.V. side
   S.C. Test: 70 V, 15 A, 600 W on H.V side
6. Draw and explain the operation of auto transformer. Also derive the expression for amount of copper saved by replacing the two winding ordinary transformer by auto transformer.(NOV/2013)
7. A 20kVA, single phase transformer has 200 turns in the primary and 40 turns in the secondary. The primary is connected to 1000V, 50Hz supply.
   Determine a) The secondary voltage on open circuit
   b) The current flowing through the two windings on full load.
   c) The maximum value of flux. (APRIL/2013)
8. Explain the principle of operation of an auto transformer. Also write advantages and disadvantages of auto transformer. (APRIL/2013)
9. Derive the equivalent circuit of a single phase two winding transformer. (NOV/2012)
10. Obtain the approximate equivalent circuit of a given 200/2000 V, single-phase 25kVA transformer having the following test results.(NOV/2012)
    O.C test: 200V, 6A, 350 W on LV side
    S.C. test: 70V, 15A, 600W on HV side
11. Derive the emf equation of a transformer. (APRIL/2012)
12. Explain OC and SC tests on single phase transformer. (APRIL/2012)

Unit -2

1. Explain the operation of single phase induction motor on the basic of double field revolving theory with neat sketch. (11) (NOV/2014)
2. Derive the equation for torque developed by three phase induction motor. Draw the torque slip curve and deduce the condition for maximum torque (11) (NOV/2014)
3. Explain the starting method of cage induction motors(APRIL/2014)
4. Explain why the single phase induction motors are not self-starting? Describe the operation of capacitor start and run motors in detail. (APRIL/2014)
5. Explain any two starting methods of three phase induction motor.(NOV/2013)
6. Explain construction and operation of stepper motor.(NOV/2013)
7. With neat sketches explain the constructional details and operation of three phase induction motor. (APRIL/2013)
8. Explain the construction and working of AC series motor. (APRIL/2013)

9. Explain the operation of star delta starter and auto transformer starter used for three phase induction motor. (NOV/2012)
10. Explain in detail about different modes of operation of stepper motor. (NOV/2012)
11. Discuss the various schemes used for speed control of 3 phase induction motor. (APRIL/2012)
12. Explain the construction and working of AC series motor. (APRIL/2012)

Unit -3

1. (a) Explain the construction and principle of operation of three phase alternator with neat sketch. (6) (NOV/2014)
   (b) What are the advantages of salient pole type construction used for synchronous machine (5) (NOV/2014)
2. Describe any two methods of determining the voltage regulation of three phase alternator (11) (NOV/2014)
3. Explain the parallel operation of alternators (APRIL/2014)
4. (a) Draw and explain the phasor diagram of a loaded alternator. (APRIL/2014)
   (b) A three phase star connected alternator is rated at 1600KVA, 13.5KV. The armature effective resistance and synchronous reactance are 1.5ohm and 30ohm respectively per phase. Calculate the percentage regulation for a load of 1280KW at power factor 0.8 leading.(APRIL/2014)
5. With neat sketch, explain the parallel operation of an alternator.(NOV/2013)
6. A 3 phase, start connected alternator revolves at 1000 rpm. The stator has 90 slots and 8 conductors per slot. The flux per pole is 0.05 Wb. Calculate the voltage generated by the machine if winding factor is 0.96. (NOV/2013)
7. Derive an expression for the induced EMF of an alternator. (APRIL/2013)
8. Explain the EMF method to determine the voltage regulation of an alternator. (APRIL/2013)
9. A 3-phase star connected alternator is rated at 1600kVA, 13500 V. The armature effective resistance and synchronous reactance are 1.5ohm and 30 ohm respectively per phase. Calculate the percentage regulation for a load of 1280 kW at power factors of a) 0.8 lagging b) 0.8 leading (NOV/2012)
10. Explain the construction and operation of an alternator. (NOV/2012)
11. Explain in detail with phasor diagram of an alternator on load. (APRIL/2012)
12. Describe the parallel operation of alternators. (APRIL/2012)

Unit -4

1. Explain the working of an instrumentation amplifier with a circuit. Give its characteristics and application (11) (NOV/2014)
2. Draw the circuit of a first order and second order butter worth active low pass filter and derive the transfer function (11) (NOV/2014)
3. (a) With neat sketches, explain the operation of instrumentation amplifier. (APRIL/2014)
   (b) Explain the analysis of differentiator. (APRIL/2014)
4. With neat circuit diagram and necessary equations, explain the II order low pass filter. (APRIL/2014)
5. Draw and explain the operation of differentiator and integrator circuits.(NOV/2013)

6. With neat circuit diagram explain the operation of adder and substractor.(NOV/2013)
7. Explain the analysis of inverting amplifier and non inverting amplifier(APRIL/2013)
8. With neat circuit diagram explain the first order low pass filter. (APRIL/2013)
9. Write short notes on i) Integrator ii) Adder-subtractor(NOV/2012)
10. Draw and explain the operation of instrumentation amplifier(NOV/2012)
11. Explain in detail about V to I converter. (APRIL/2012)
12. Write short notes on a) adder b) subtractor. (APRIL/2012)

Unit -5

1. (a) Explain the functional block diagram of 555 timer (8) (NOV/2014)
   (b) Write about the features of 555 timer. (3) (NOV/2014)
2. Draw the block diagram of an Astablemultivibrator using 555 timer and derive an expression for its frequency of oscillation. (11) (NOV/2014)
3. Explain the operation of Astablemultivibrator. (APRIL/2014)
4. Draw and explain the operation of shift registers. (APRIL/2014)
5. Explain the operation of Astablemultivibrator with neat sketch.(NOV/2013)
6. Draw and explain the operation register. (NOV/2013)
7. Explain the operation of monostablemultivibrator. (APRIL/2013)
8. Draw and explain the operation and truth table of UP-DOWN counter. (APRIL/2013)
9. Draw and explain the functional diagram of a 555 timer.(NOV/2012)
10. Explain the working of serial in – serial out shift register with logic diagram.(NOV/2012)
11. Explain in detail about the astablemultivibrator. (APRIL/2012)
12. Explain the operation of UP/DOWN counter(APRIL/2012)